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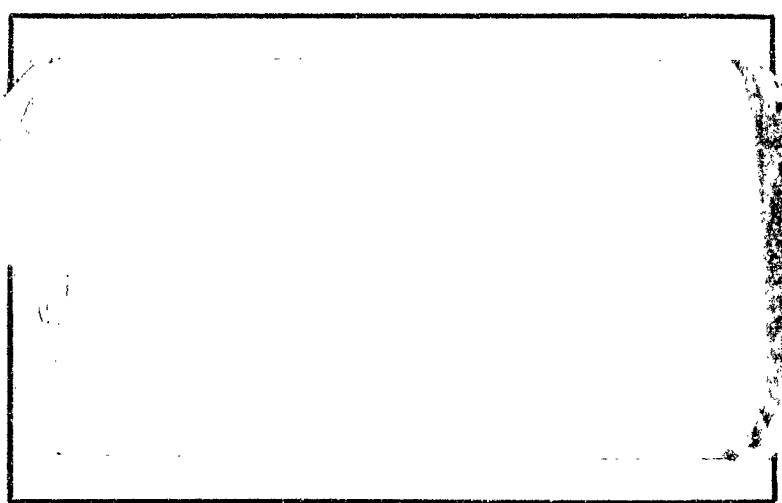
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The Bermuda-Azores High Pressure Cell;
its surface wind circulation

by

Joseph Chase

Technical Report No. 20
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July 1951

APPROVED FOR DISTRIBUTION



Director

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Abstract

The Bermuda-Azores High is associated with a clockwise wind circulation over the surface of the North Atlantic Ocean. This circulation is oval shaped with the long axis running east-west. From the standpoint of averages over several years it is a very regular circulation. When considered for shorter periods, however, its regularity vanishes at times due to the influence of other meteorological phenomena. These phenomena make convenient handles to denote the various types of irregularities, which frequently persist for periods of from one to six weeks.

Introduction

The title, "The Bermuda-Azores High Pressure Cell" refers to that cell of high atmospheric pressure usually located in the North Atlantic Ocean between the 20th and 50th parallels. This "high" is known by several other names among which are "The Azores High", "The Bermuda High", "The Mid-Atlantic High", and "The Semi-permanent North Atlantic High". The words Bermuda-Azores were chosen as being somewhat more descriptive of the high's average position and domain.

It is the purpose of this paper to describe briefly, for oceanographers, the habits of this high, discussing its average location and shape, and the clockwise circulation of surface winds associated with it, as well as some anomalies of location, shape, and circulation.

It is assumed that any changes in average pressure which may have occurred in the last half century, can be ignored in the discussion.

The maps used for the study are the:

1. Historical Weather Maps, Northern Hemisphere, Sea Level (Weather Bureau, 1943).
2. Normal Weather Maps, Northern Hemisphere, Sea Level Pressure (Weather Bureau, 1946).

These maps cover the period beginning January 1, 1899 and ending June 30, 1939. The former are daily maps and the latter are averages for the 40-1/2 years.

Annual Pressure Distribution

The average pressure distribution for the entire period of the maps shows two main features in the North Atlantic, viz: the so-called Icelandic Low and the Bermuda-Azores High. These features may be seen in Figure 1. The "Icelandic Low" is centered just east of the southern tip of Greenland at about 62°N., 38°W., and is elongated in a curve from Davis Strait to Novaya Zemlya. The Bermuda-Azores High is centered some 600 miles southwest of the Azores at 32°N., 33°W., and is elongated east-west in a curve from the Georgia-Carolina area to Spain. It is part of a belt of high pressure encircling the earth near the 30th parallel (i.e., the Horse Latitudes).

In summer, thermal conditions resist the formation of high pressure over the land and the Horse Latitude high pressure belt is continuous only over the cooler oceans. In winter, the belt

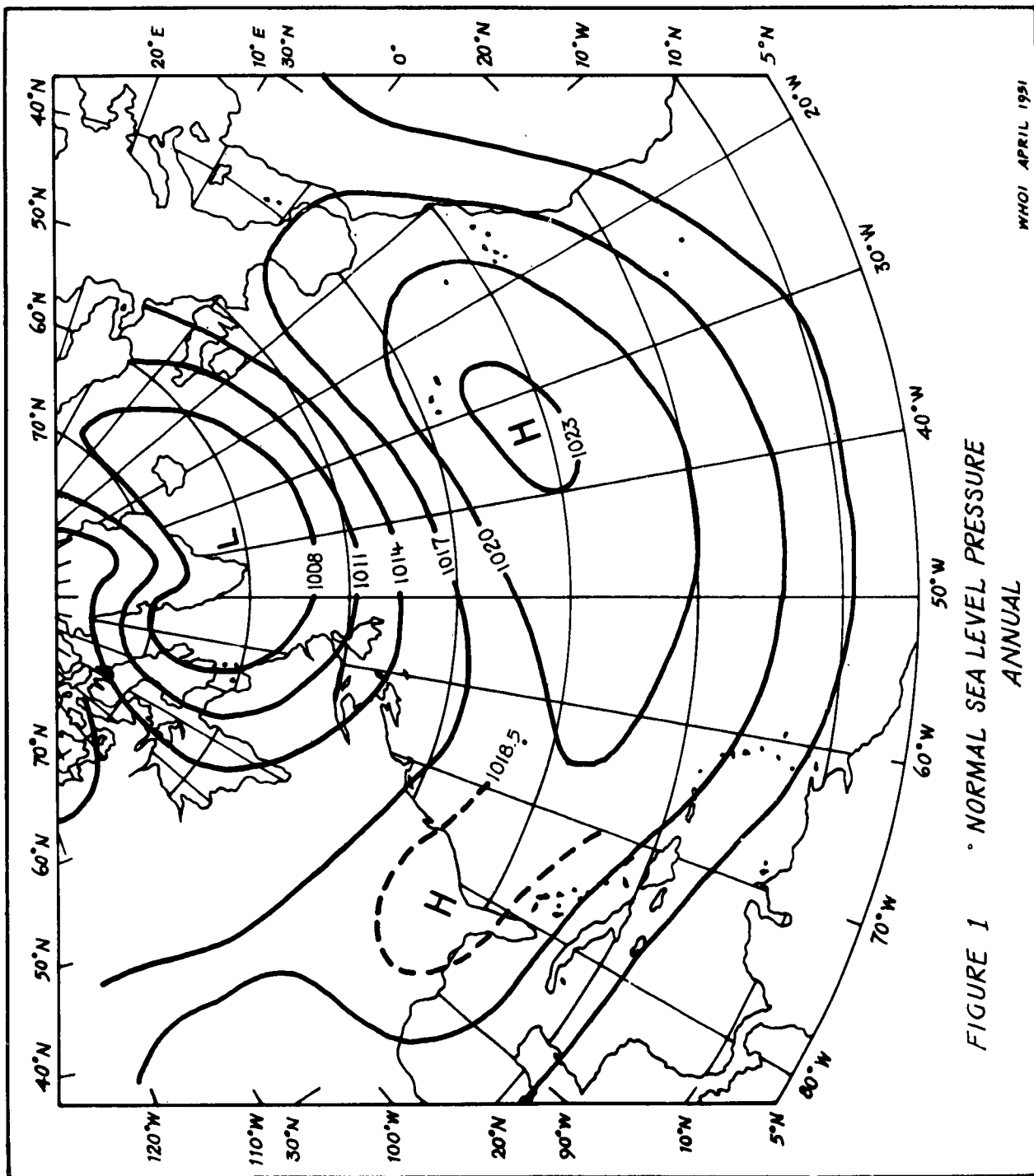
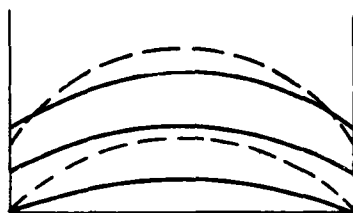
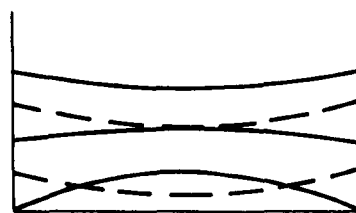


FIGURE 1 ° NORMAL SEA LEVEL PRESSURE
ANNUAL



A

WARM HIGH



B

COLD HIGH

SOLID CURVES = ISOBARIC SURFACES

PRESSURE DECREASING WITH HEIGHT.

DASHED CURVES = ISOTHERMAL SURFACES

TEMPERATURE DECREASING WITH HEIGHT.

FIGURE 2

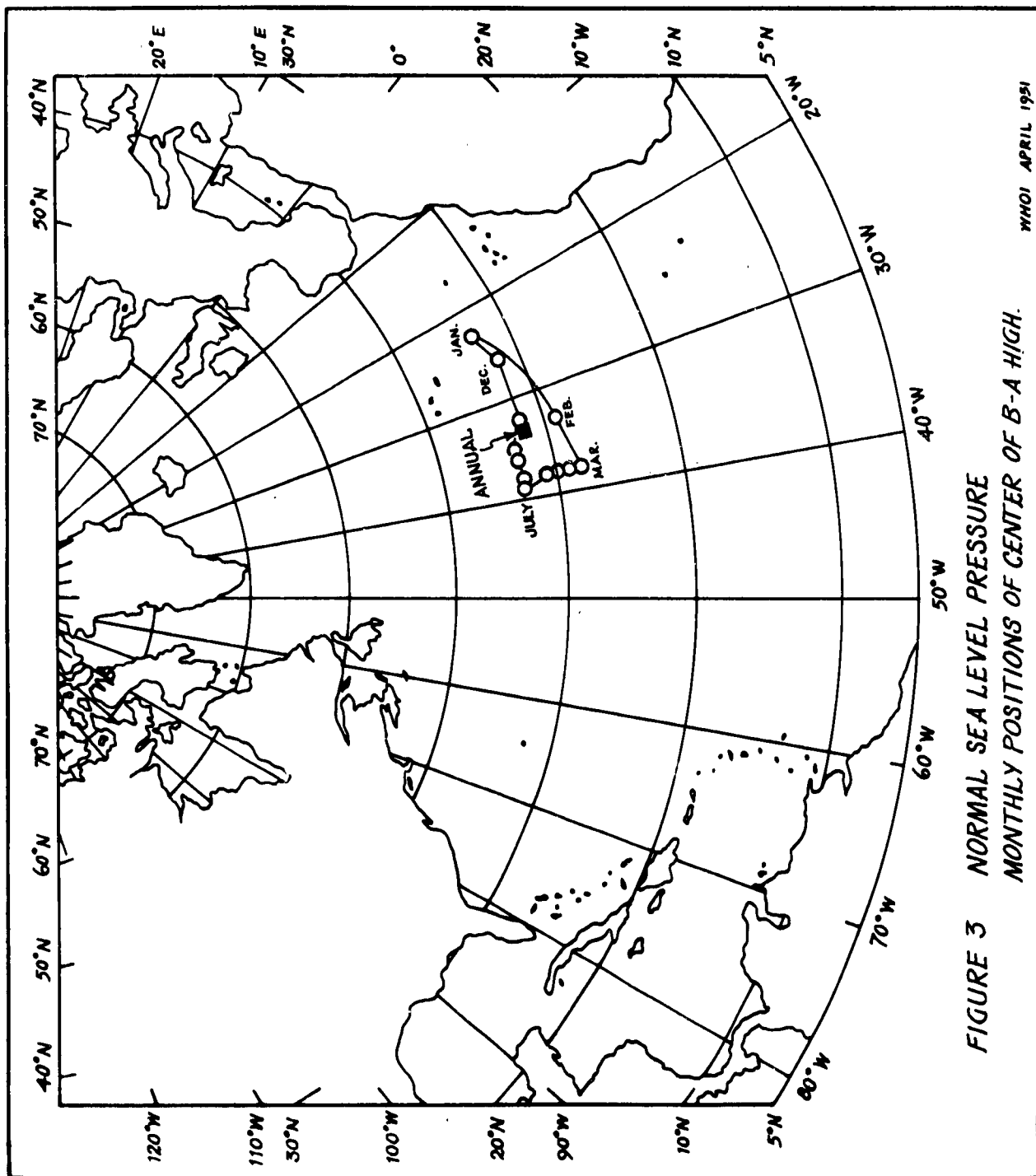
can readily be traced around the globe, but weak troughs, one over the Gulf Stream and the other over the Mediterranean, partially separate the Bermuda-Azores High from the rest of the belt. In the annual picture, therefore, we see the Bermuda-Azores High as a separate cell, bounded on the north by the prevailing Westerlies, on the south the by Trade Winds, on the east by northerlies and on the west by weak southerlies. The strongest of these winds are the Westerlies. The average wind force in the area of the Westerlies is much stronger than indicated by the average pressure gradient. The difference is due to the great variability of wind direction in that area especially in winter. Changing wind directions greatly lower the average gradient at the east end of the high and leave a very gentle net southerly flow at the west end. While wind strengths are generally lower in the Trades than in other sectors, the directions there are much more constant and this gives an average gradient about as strong as that in the Westerlies.

The winds flow clockwise around the high at an angle of about 20° to the left of the isobars (toward lower pressure) but deviate by as much of an angle as 70° in some instances in tropical regions. The deviation is largest in the Cape Verde Island region, but diminishes rapidly to 20° to 30° in the rest of the Trades and is 10° to 20° in the Westerlies and at the east and west ends.

The annual average position of the center of the Bermuda-Azores High is about twice as far from Charlestown, S. C., as from Casablanca.

Structure of Highs

The Bermuda-Azores High is a warm high; i.e., it is warmer at the center than at the edges. Since water vapor content differences between the center and the edges are negligible, it follows that in the center, the air at a given isobaric surface is rarer and therefore the vertical distance between two isobaric surfaces greater than at the edges. This being so the high persists into the higher levels of the troposphere. In contrast to this, is the situation in the cold (continental) highs of higher latitudes. In this latter case the distance between two given isobaric surfaces is less in the colder denser air of the center than at the edges and the high must turn into a low at altitude. Figures 2A and 2B are cross sections through the two types of high.



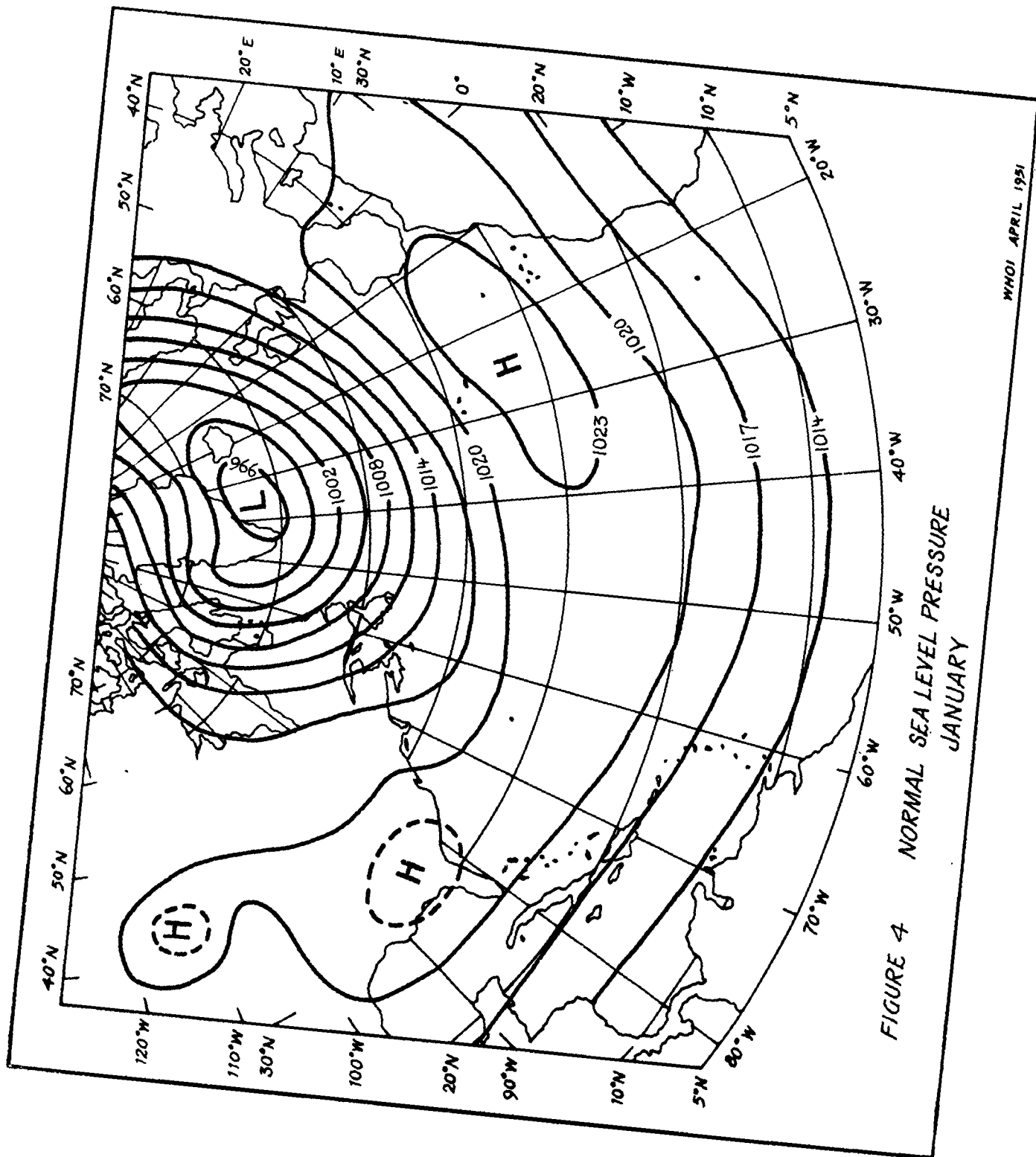


FIGURE 4 NORMAL SEA LEVEL PRESSURE
JANUARY

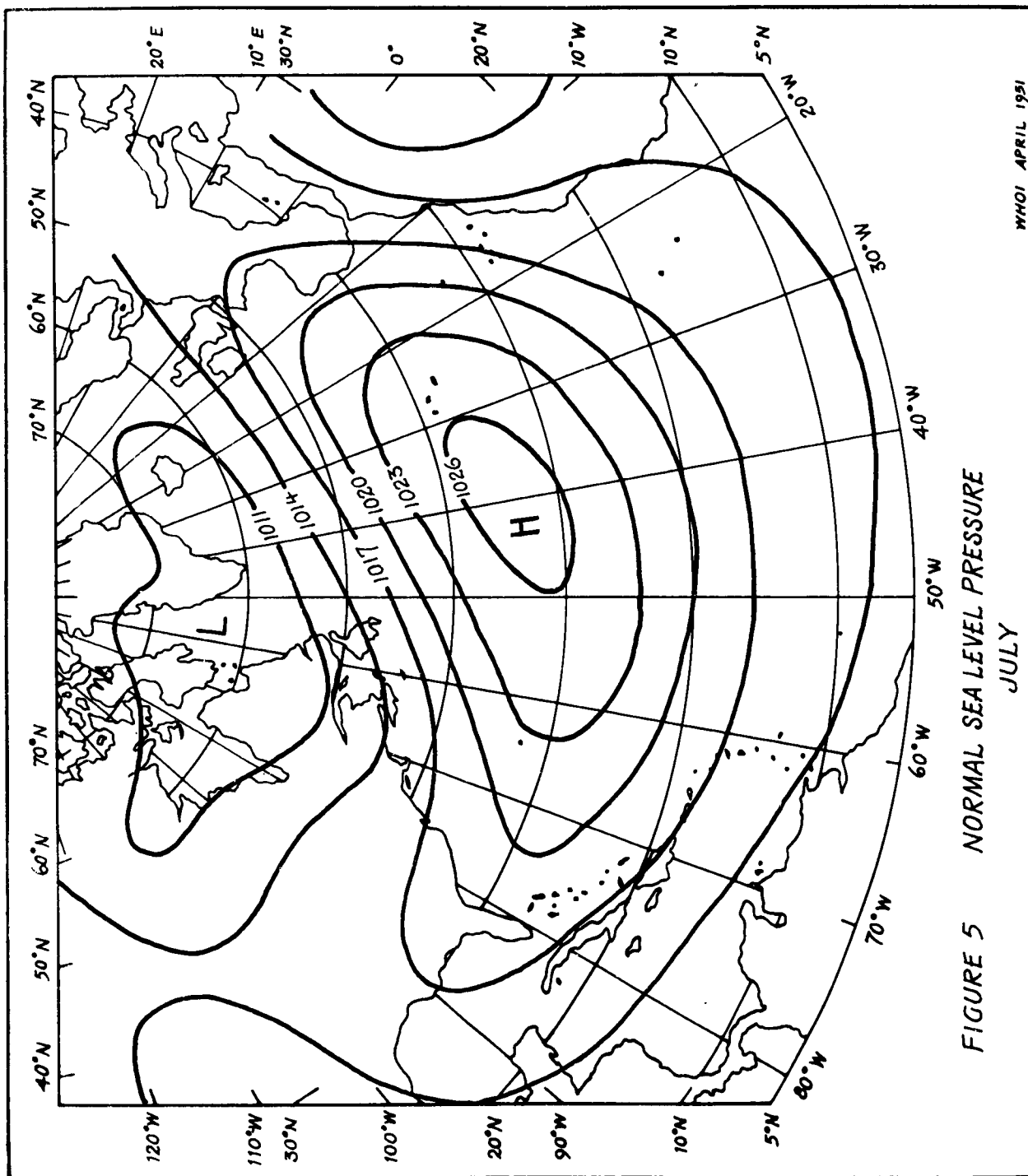
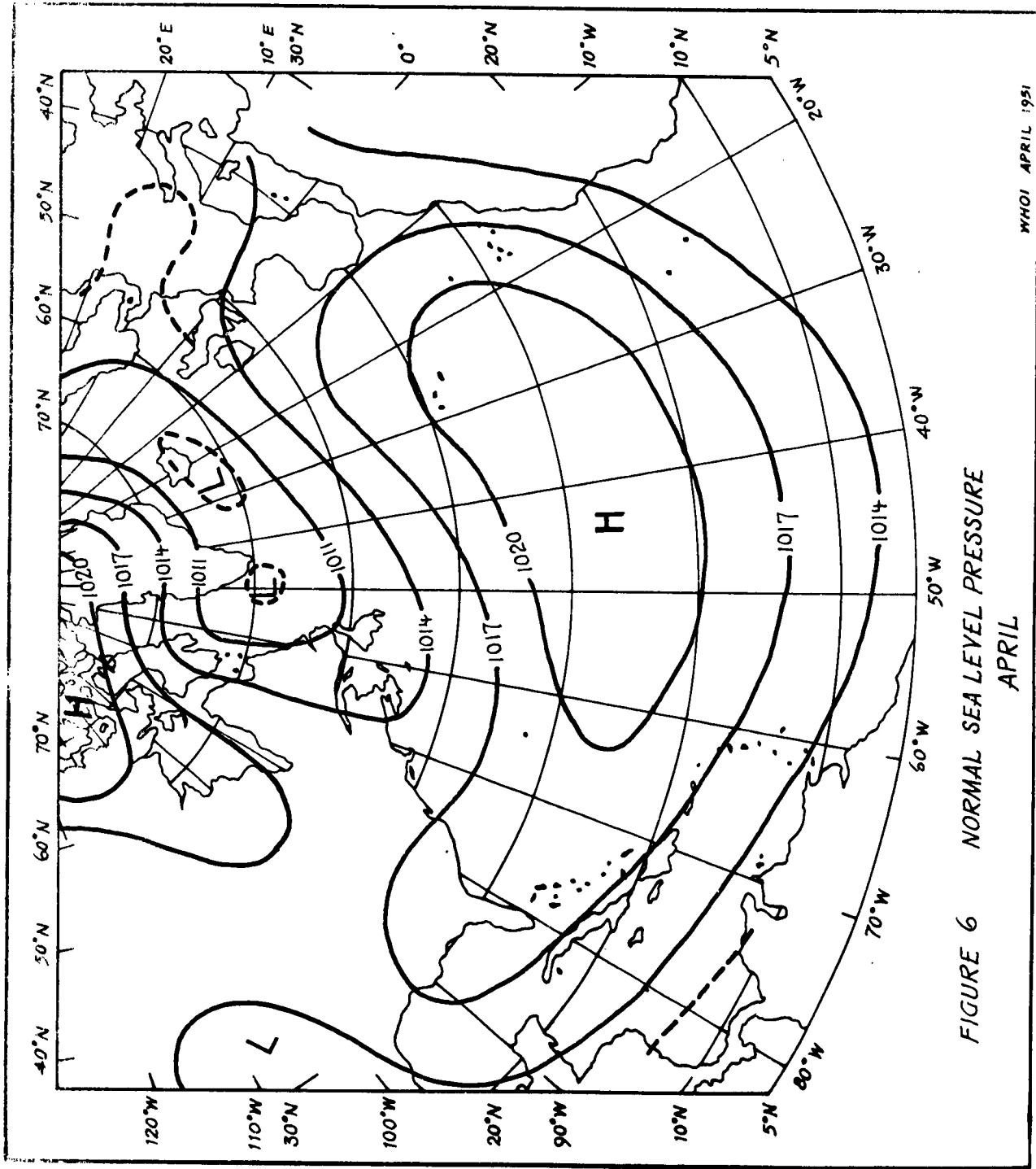


FIGURE 5 NORMAL SEA LEVEL PRESSURE
JULY

WHOI APRIL 1951



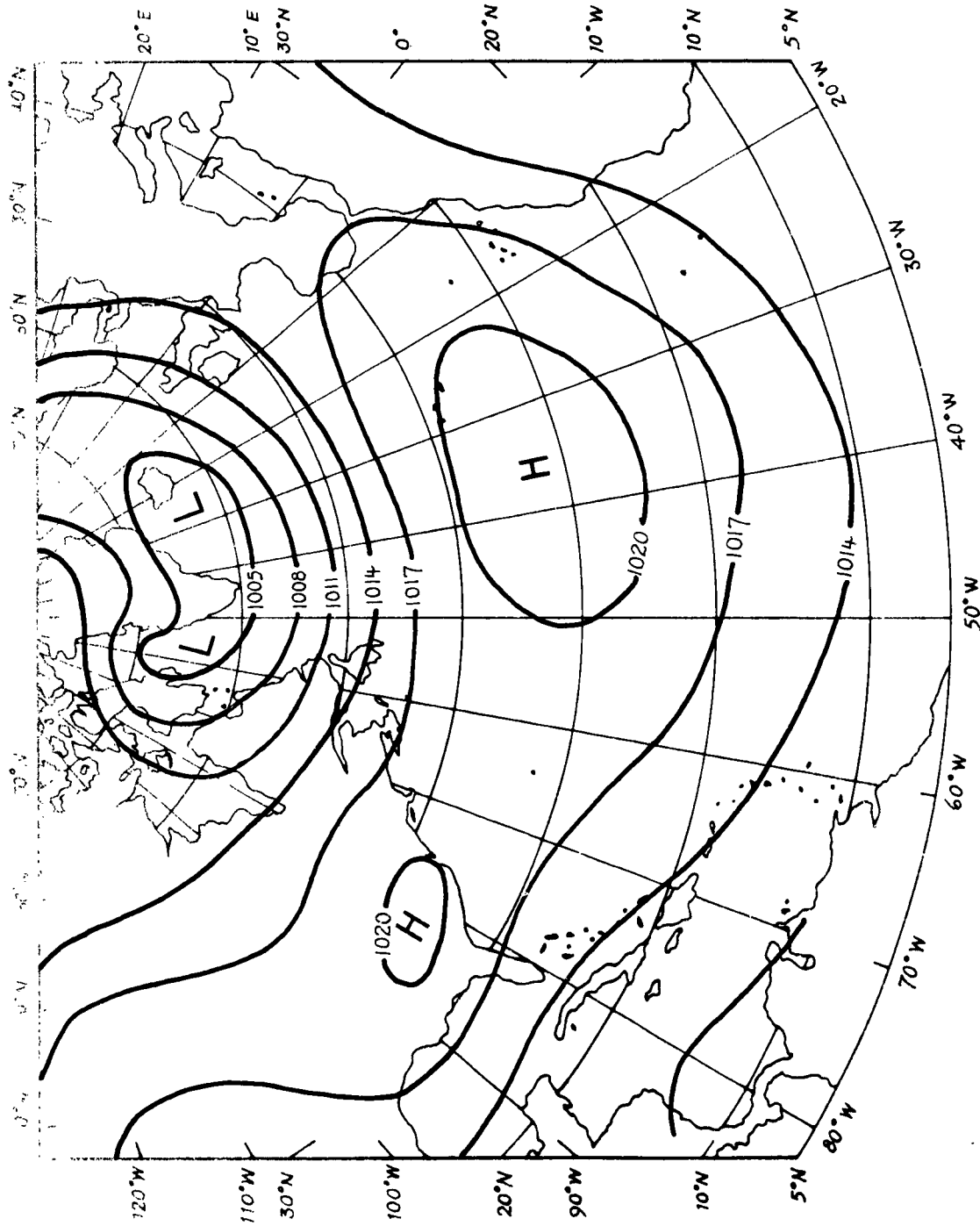


FIGURE 7 NORMAL SEA LEVEL PRESSURE
OCTOBER

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Formation of Highs

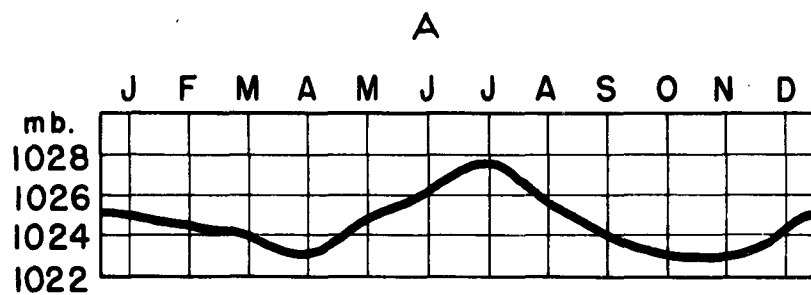
In the general circulation ✓ of the atmosphere, air rising in the tropics because of heating is carried poleward to the Horse Latitudes by upper winds. It cools and becomes denser as it moves poleward and descends in the Horse Latitudes to feed the warm highs situated there. The air escapes north and south in divergence at the surface. Air rising along the polar front at roughly the 60th parallel is carried poleward by upper winds and descends into the cold highs of polar regions. This air escapes at the surface not only in divergence but also in what are called polar outbreaks. These polar outbreaks are cold shallow highs which detach themselves from the main polar high and migrate toward lower latitudes (i.e., toward the warm highs of the Horse Latitudes). As will be seen later, the entrance of these migrating cold highs into the area of the Bermuda-Azores High has an effect on the circulation there.

Average Pressure Distribution by Months

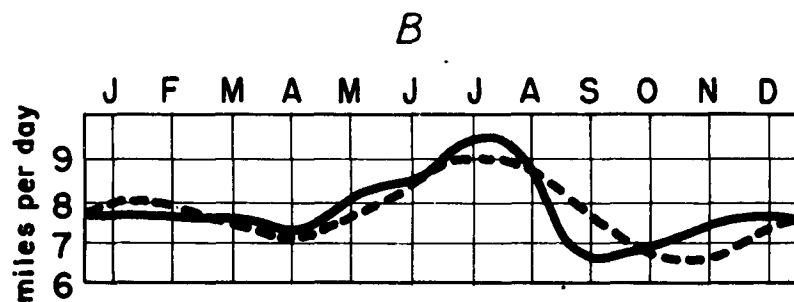
The positions of the centers of the Bermuda-Azores High on the monthly Normal Weather Maps make a rather orderly path about the annual position of the center, (32°N. , 33°W.). The easterly positions of the centers for November through February are the result of a greater incidence of high pressure over Europe and North Africa in those months and the linkage of this high pressure with the Bermuda-Azores High. The centers for the remaining months are closely grouped near 38°W. All of the centers are plotted in Figure 3,

The general appearance of the mean monthly pressure distributions is similar to that of the annual average. Although the Westerlies are normally stronger in winter than in summer, the circulation around the Bermuda-Azores High, when taken as a whole, is greater in summer. The mean maps for January and July (Figs. 4 & 5) illustrate this fact. In July the Trades are stronger in proportion to the increased pressure gradient and the east and west ends of the high are much better developed. The Westerlies show a decrease in width of band and in pressure gradient. The decrease is greatest in the area north of 50°N. South of that parallel, the average Westerlies are nearly as strong as in winter. This is the result of more steadiness of direction in summer rather than of high velocities. The other months represent parts of the gradual spring and fall transitions between January and July. Figures 6 and 7 are for April and October, the mid-points in the transitions. Note the weak northerly flow off Hatteras

✓ More complete descriptions of the general circulation may be found in Rossby 1941 and Willett 1944.

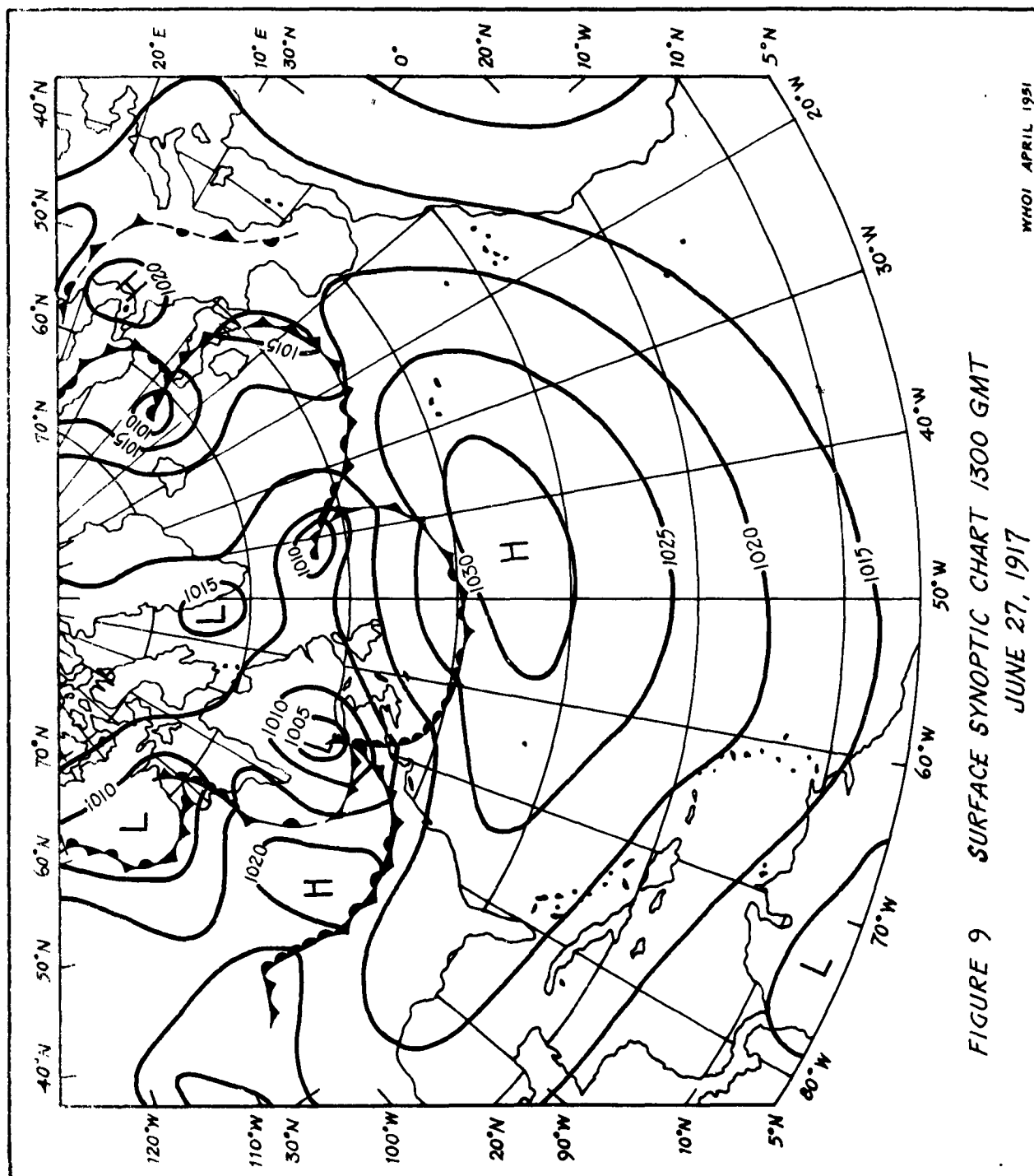


CENTER PRESSURE B-A HIGH
 — AVERAGE 1899 - 1939



CURRENT SPEEDS - FUGLISTER TR [✱]15
 — OBSERVED
 - - - - CALCULATED COMBINATION
 ANNUAL & SEMI-ANNUAL
 PERIODS. (HARMONIC ANALYSIS)

FIGURE 8



in October and in January which is caused by a small average high over the land. This high and this reversal of normal flow are also present in November and December, and are strongest in November.

The highest pressure in the Bermuda-Azores High for the monthly mean charts varies between 1023 mb. (April, October, November) and 1027.5 mb. (July). Figure 8A is a graph of these highest pressures. While it is not the purpose of this paper to discuss ocean currents it is interesting to note that this graph with its maxima in January and July and minima in April and October-November is remarkably close in date and amplitude to the graphs for ocean current strength in a test rectangle off the Guianas (Fuglister, 1951) (Figure 8B).

The center pressure is in some degree a measure of the relative pressure gradient and surface wind over this test rectangle, if the following conditions obtain: (1) average maps with smoothed isobars, (2) small (2 mb.) variation in mean monthly pressure along the Guiana coast, (3) monthly positions of the center of the Bermuda-Azores High confined to a relatively small area. Since these three conditions are satisfied in the Normal Weather Maps the correlation suggests that variations in the surface wind are directly and within a short time reflected in the variations of velocity of ocean currents in the area of the test rectangle at least.

Daily Weather Maps

A large proportion of the daily maps resemble the average maps in position and orientation of the Bermuda-Azores High and in the circulation about it. These situations are most common in the summer (frequency estimated at some 60% of the time and least common in winter (about 30%)). The frequency for fall is slightly higher than spring.

The situation in Figure 9 is a typical summer "good" circulation; i.e., "good" in respect to speed and direction of wind clockwise about a normally centered high. (Note that the isobars are drawn for 5 mb. intervals on the daily maps while 3 mb. spacing is used on the average maps). The gradient in the Trades and at the east and west ends of the Bermuda-Azores High is well developed. The Westerlies are broken up north of 50°N. due to the overthrow of the reign of the Icelandic Low. The Bermuda-Azores High, however, is contributing* its share toward the production of the Westerlies and a respectable gradient can be seen south of 50°N.

* This and later statements marked with an *, although not necessarily cause an effect relationships in a pure physical sense, are found useful in description.

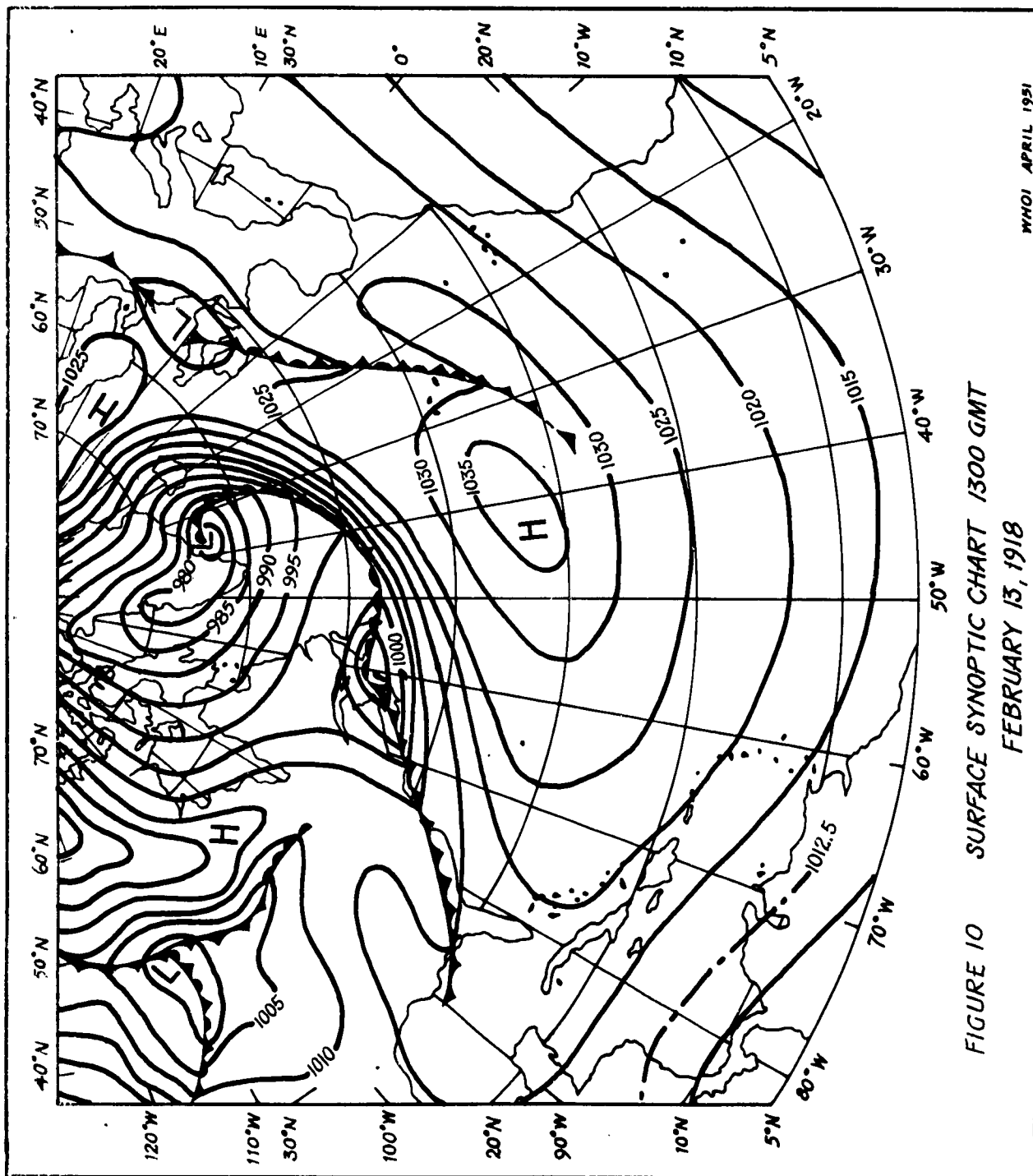


FIGURE 10 SURFACE SYNOPTIC CHART 1300 GMT
FEBRUARY 13, 1918

In January of 1918, wind circulation about the Bermuda-Azores High was far below average. In the next month, however, the circulation became far better than average. The map of February 13, 1918 (Fig. 10) is typical of that month. The Bermuda-Azores High is close to its normal position southwest of the Azores, and has the very high value for center pressure of 1037 mb. The resultant strong gradient flow starts at the African coast, runs to the Caribbean in a wide band then turns north in a good "west end" flow. North of Bermuda it is joined by strong Westerlies associated with a frontal wave in the Maritimes and heads eastward to Europe. The one weak sector in this circulation is at the "east end" in the area of an old occlusion. The Icelandic Low is in normal position and consequently the Westerlies extend to higher latitudes than in the previous example.

Interruptions to Normal Circulation

While about half of the daily maps show a "normal" circulation, the remainder contain some interruptions in that circulation. Such interruptions occur whenever the wind direction turns from the normal or when its velocity is below normal. A study of interruptions reveals that they are not a collection of freak situations but are rather the results of normal meteorological phenomena and may be classified according to the phenomena, which produce* them.

The types of interruptions to normal circulation delineated here are caused by the following:

1. Fronts
2. Stagnant Lows
3. Linkage of the Bermuda-Azores High to Continental
H highs
 - a. uniting
 - b. replacement
4. Hurricanes

The percentages of frequency quoted in the paper for the various types are estimates based on perusal of the 40-1/2 year daily series.

Fronts

Some fronts move along the northern side of the Bermuda-Azores High without interrupting the Westerlies much. In many cases they serve to increase the pressure gradient and conse-

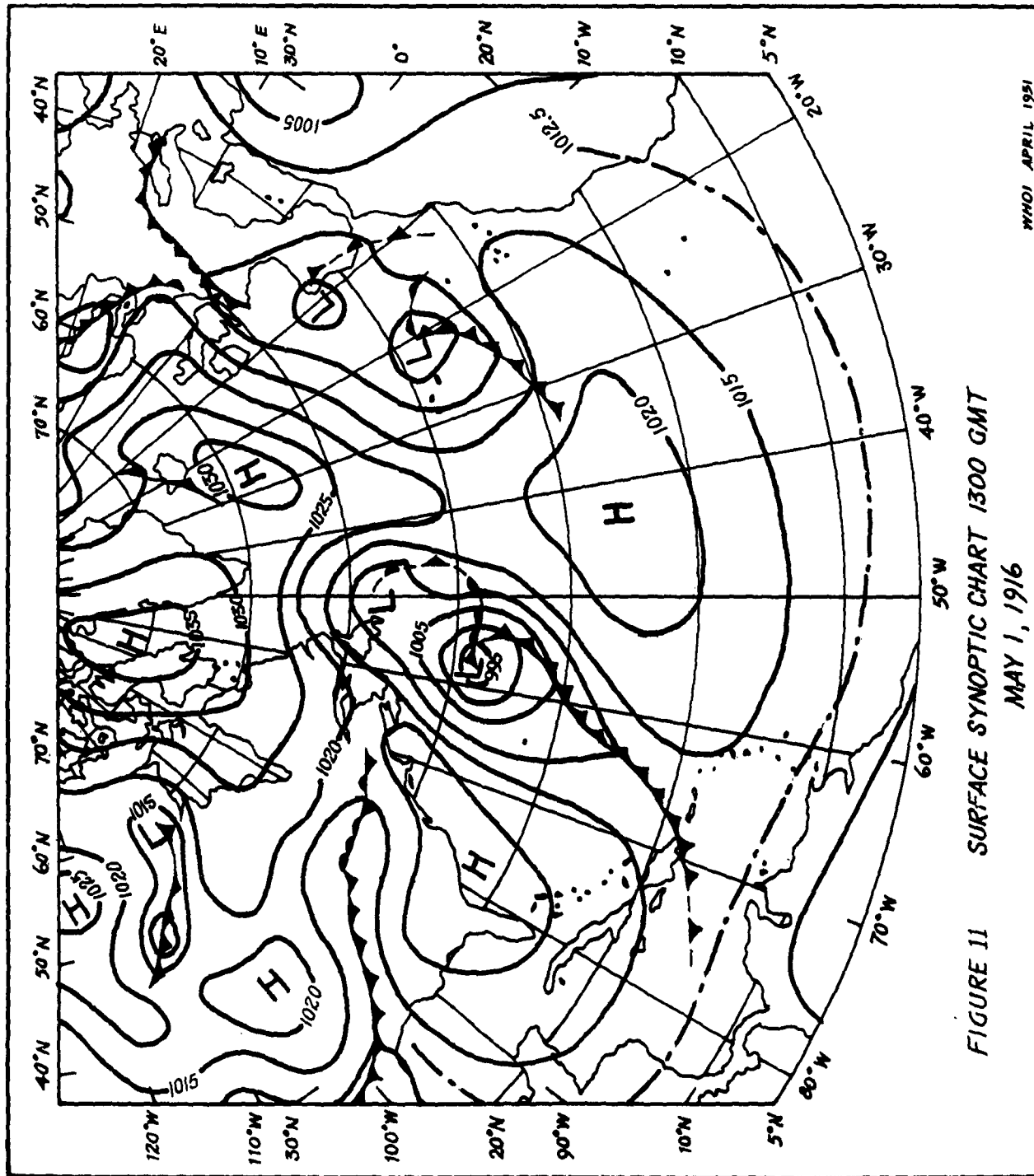
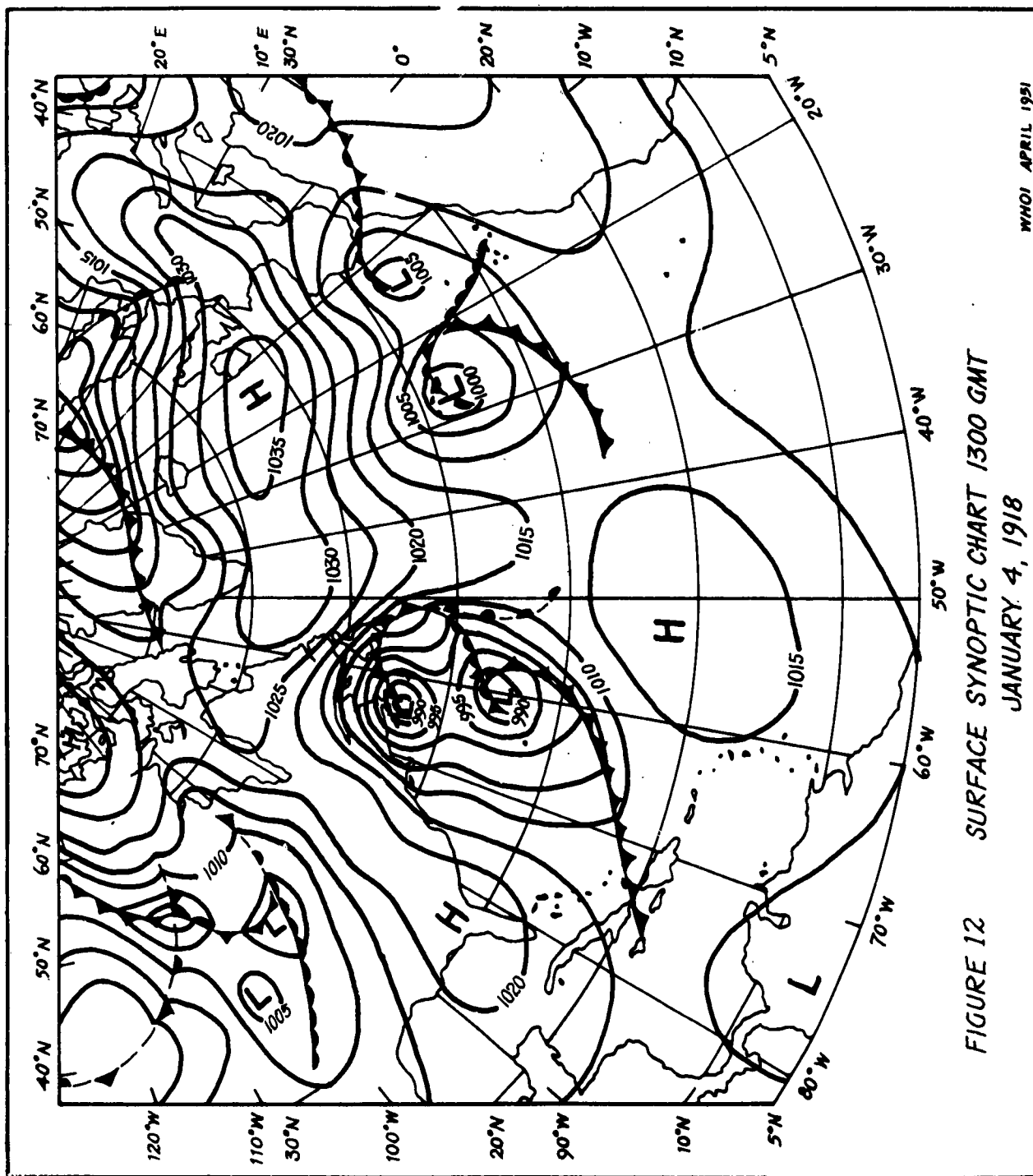
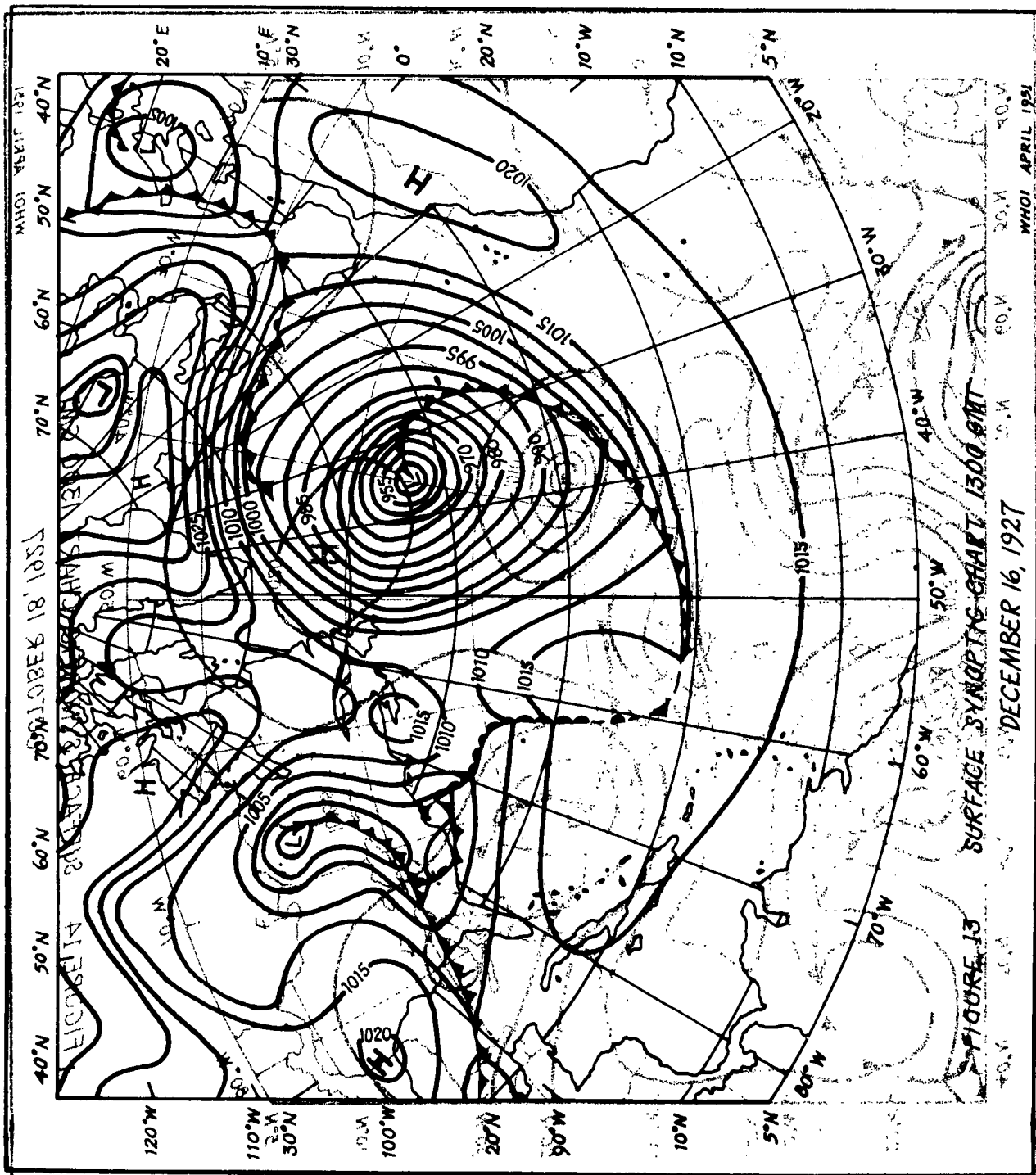
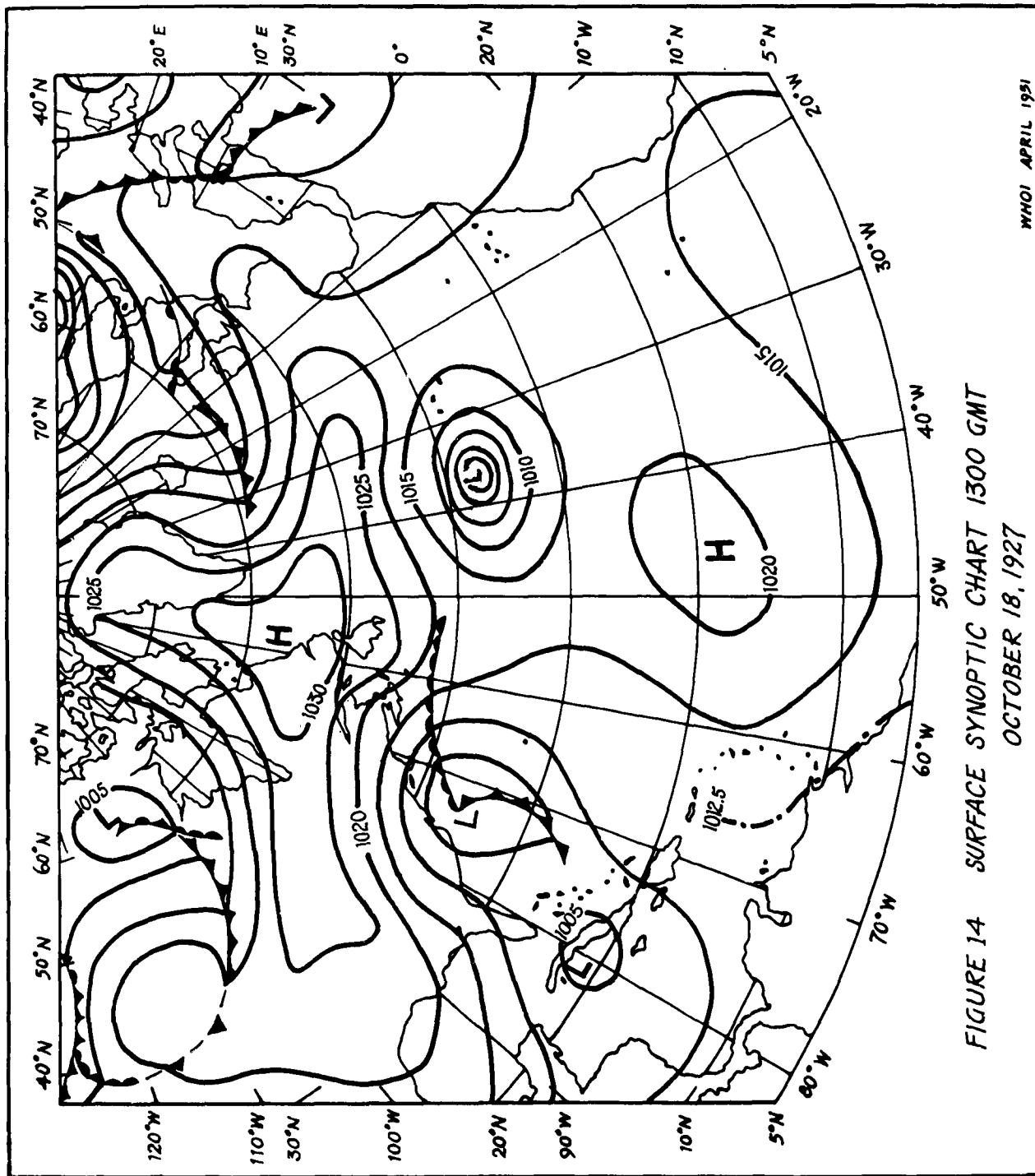


FIGURE 11 SURFACE SYNOPTIC CHART 1300 GMT
MAY 1, 1916







quently the speed of the Westerlies. Other fronts, however, elbow* their way into the general area of the Bermuda-Azores High. They cause wind directions to turn away from normal even to the point of reversal.

Two frontal systems shown in Figure 11 have weakened the Bermuda-Azores High and forced it south of its normal position. They have caused northerly winds from Newfoundland to the Bahamas, variable wind directions off Portugal and winds from the northeast and southeast between Newfoundland and Europe. The Trades are about average except for a break near Puerto Rico. A similar description fits Figure 12, but here the circulation about the frontal systems is stronger and the Bermuda-Azores High is weaker and its position farther away from normal. The Trades are strong only off the Guiana coast and west winds are found just north of Puerto Rico. The frequency figures for frontal interruptions are 50% of the time in winter; i.e., half of all winter maps, 40% in spring, 25% in summer, and 30% in fall. While any one front will normally cross the ocean from the Carolinas to Portugal in about a week, a series of fronts can extend a period of frontal interruptions to three to four weeks. When the interruptions caused by one front persist longer than one week the situation can often be classified under "Stagnant Lows".

Stagnant Lows

The stagnant low in the Atlantic not to be confused with the semi-permanent Icelandic Low, usually wanders about in some Atlantic area for 1 to 2 weeks before finding and taking* an escape route from the area. After a 2 to 5 day break, another stagnant low often appears somewhere in the Atlantic so that the duration of this type of interruption may be 4 to 6 weeks if we except the short breaks. Perhaps the most frequent Atlantic areas for stagnant lows to be found in are:

- a. Southeast of Newfoundland
- b. The Azores
- c. West of Ireland
- d. Between Bermuda and the Azores

Figure 13 shows a stagnant low which wandered about in the area southeast of Newfoundland for about 10 days before escaping eastward. It was preceded by a stagnant low of short duration in the Bay of Biscay and followed by one between Bermuda and the Azores. Figure 14 shows a stagnant low near the Azores which persisted for 16 days after which it weakened and split, one part escaping northeastward and the other southwestward.

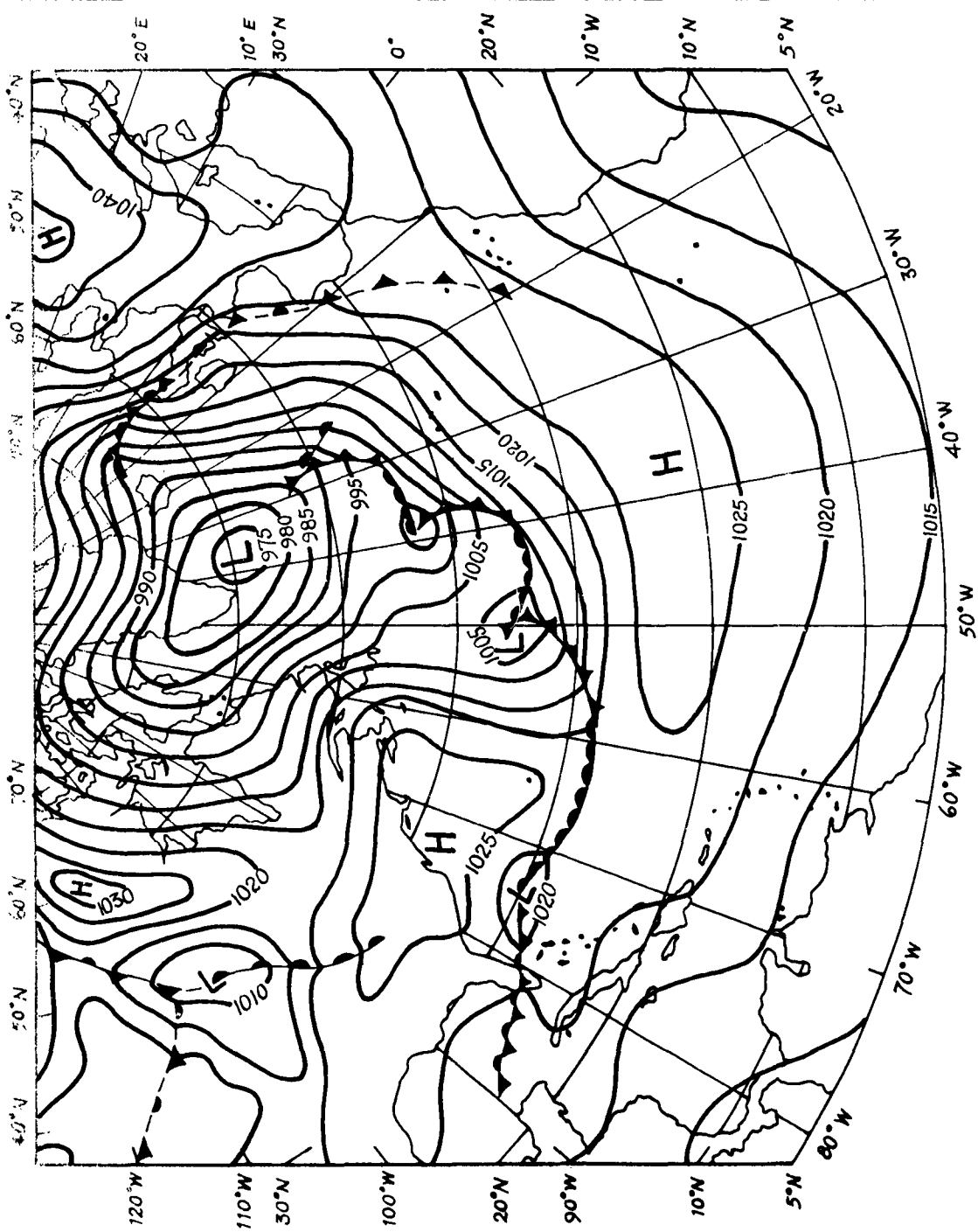


FIGURE 16 SURFACE SYNOPTIC CHART 1300 GMT
FEBRUARY 2, 1918

WHOI APRIL 1951

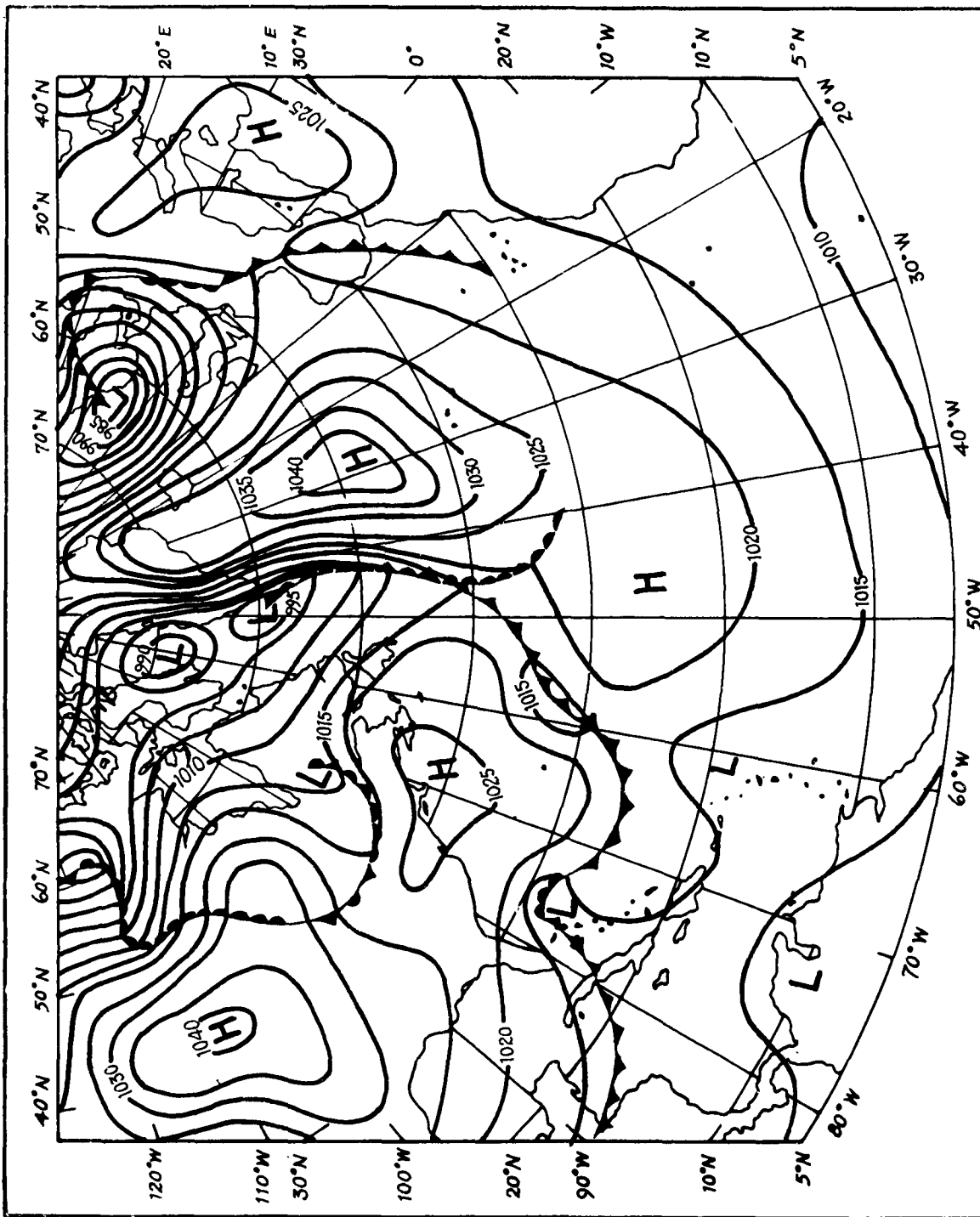
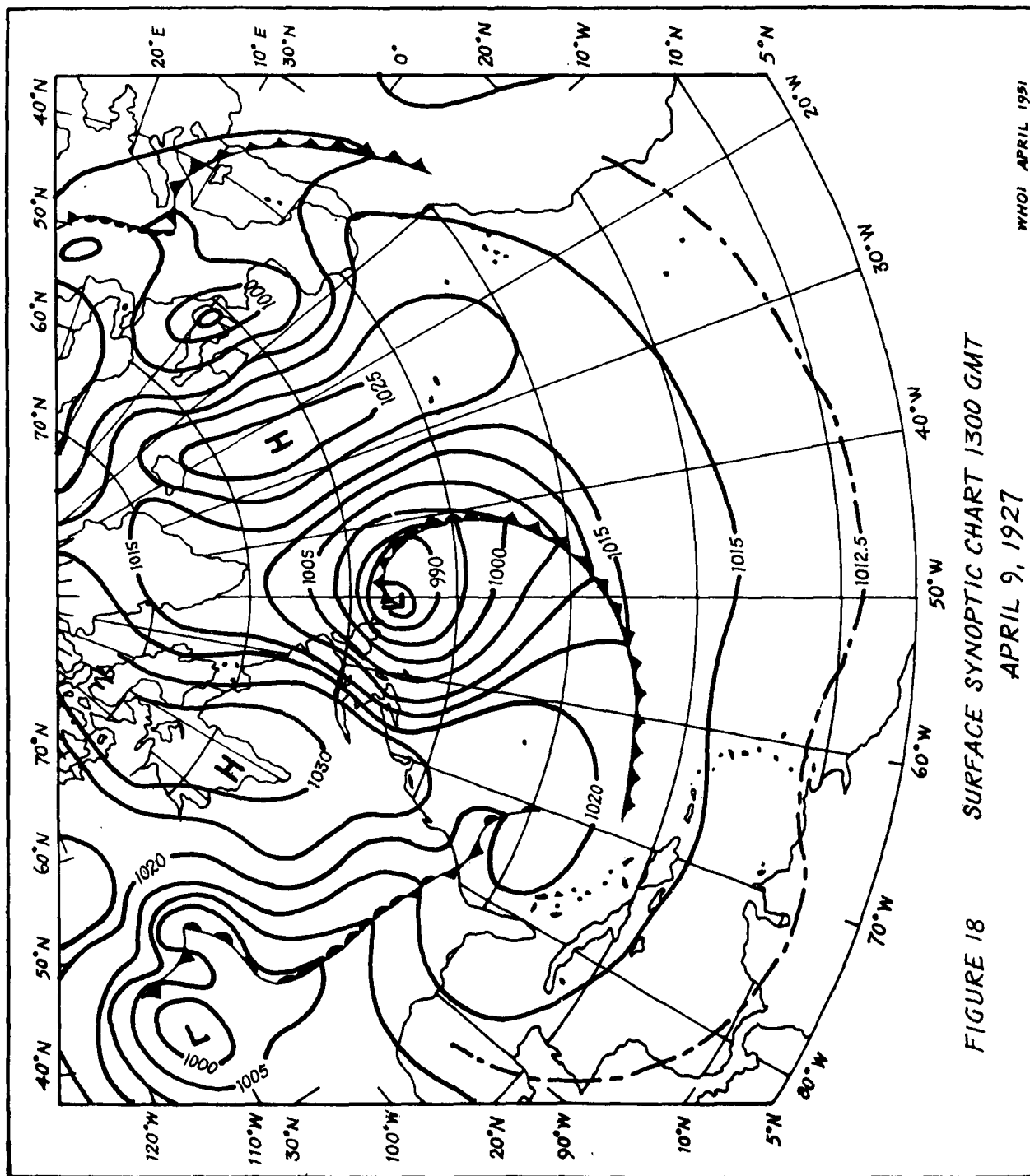


FIGURE 17 SURFACE SYNOPTIC CHART 1300 GMT
DECEMBER 7, 1918



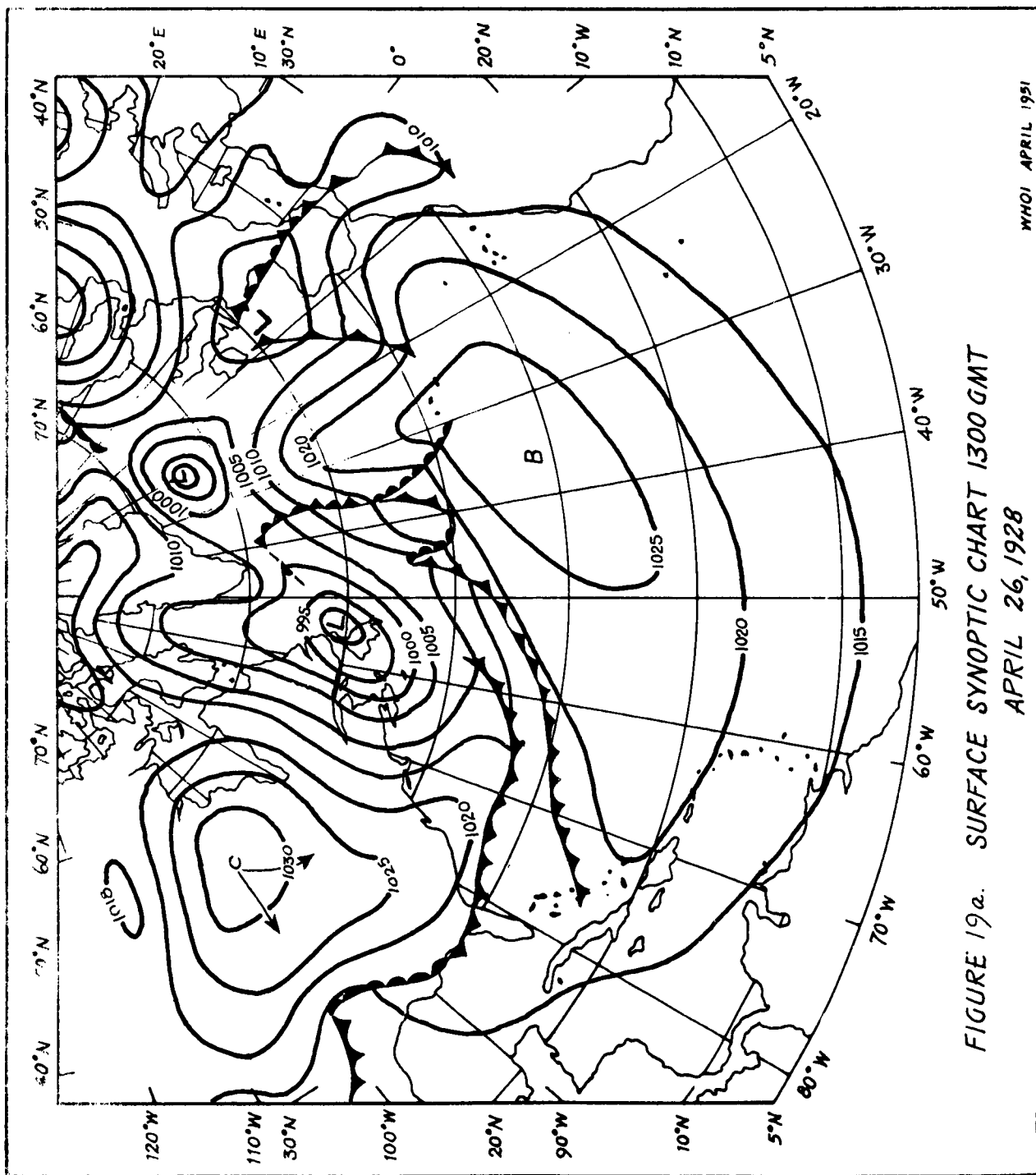
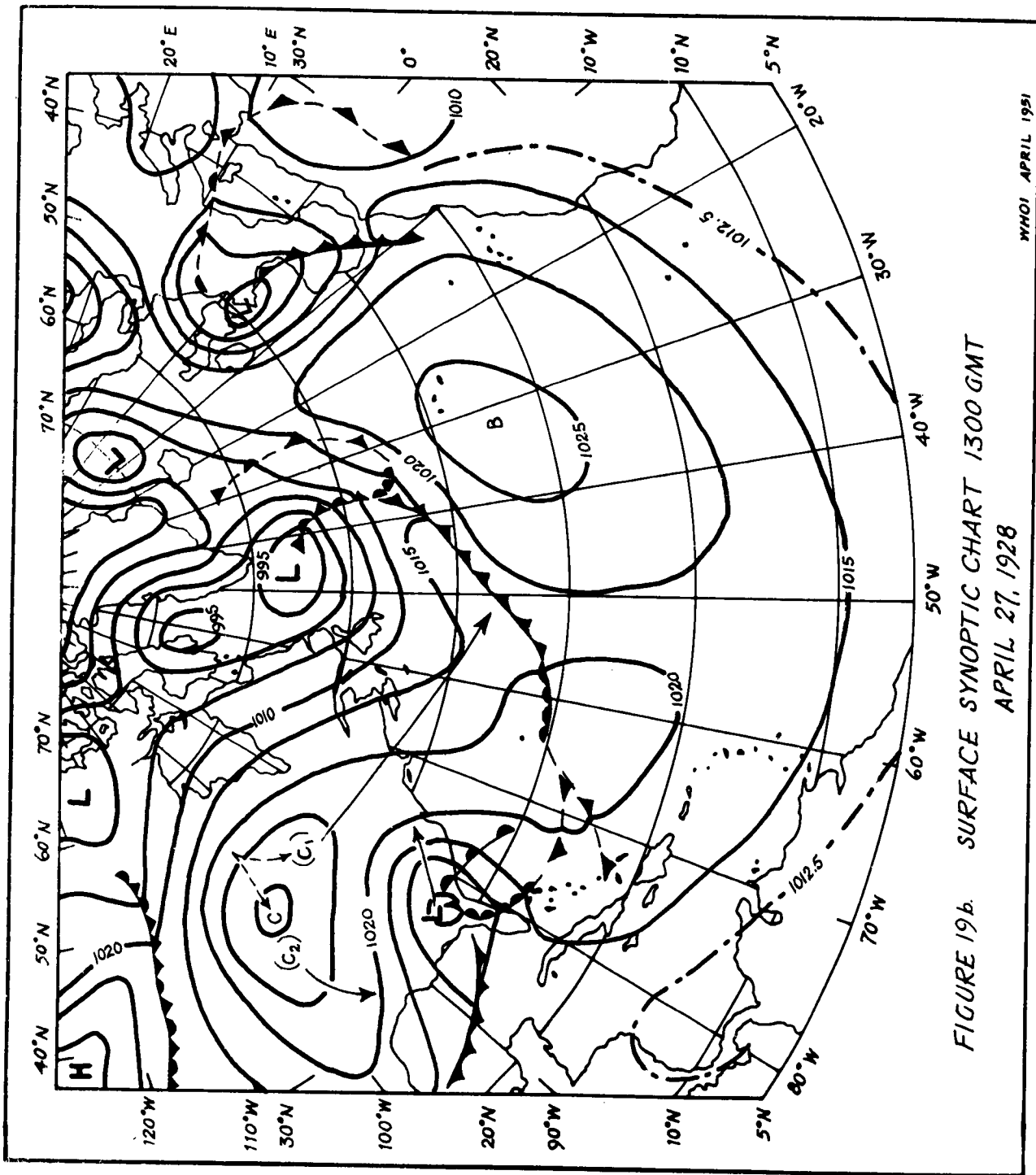


FIGURE 19a. SURFACE SYNOPTIC CHART 1300 GMT
APRIL 26, 1928



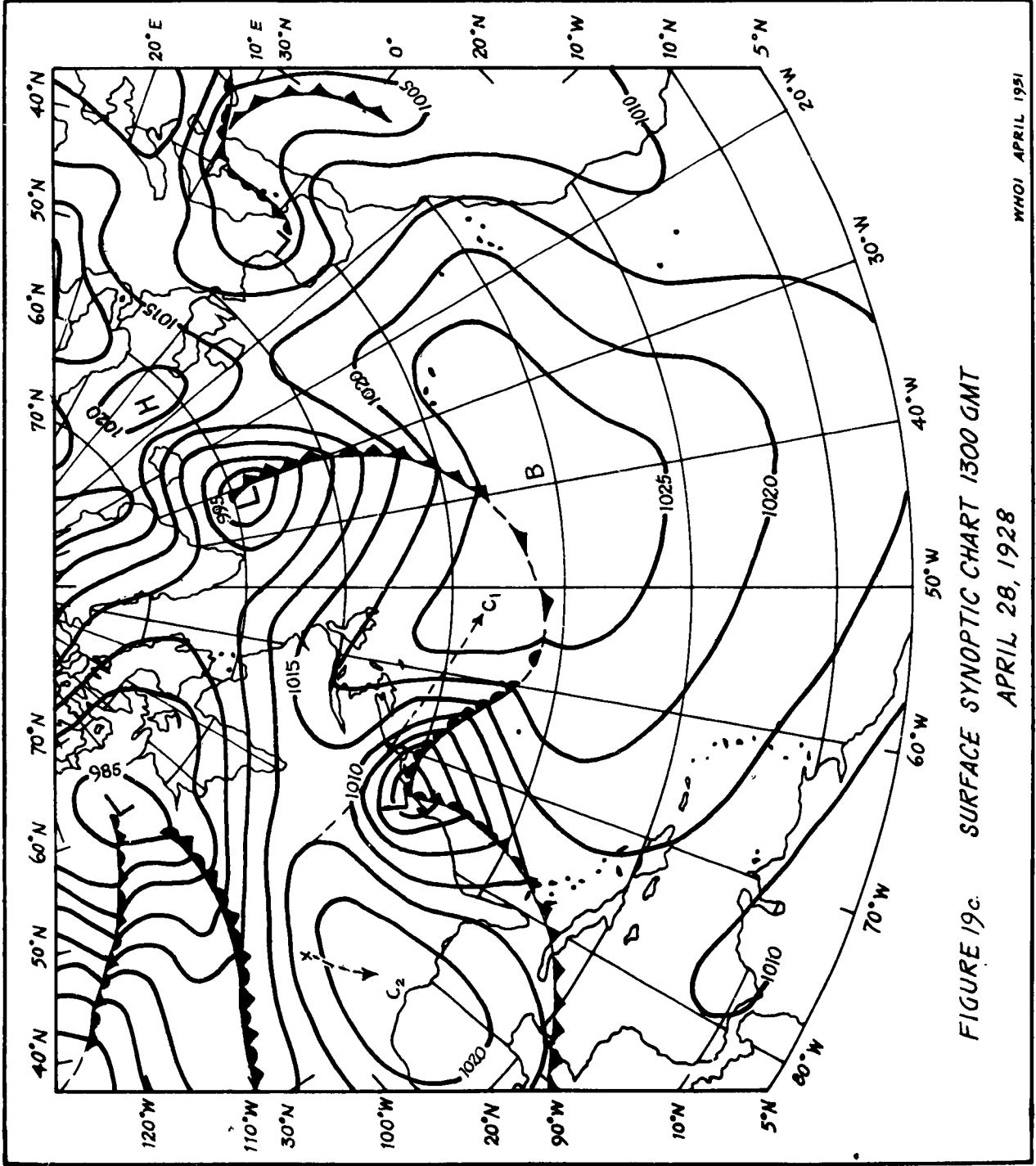


FIGURE 19c. SURFACE SYNOPTIC CHART 1300 GMT
APRIL 28, 1928

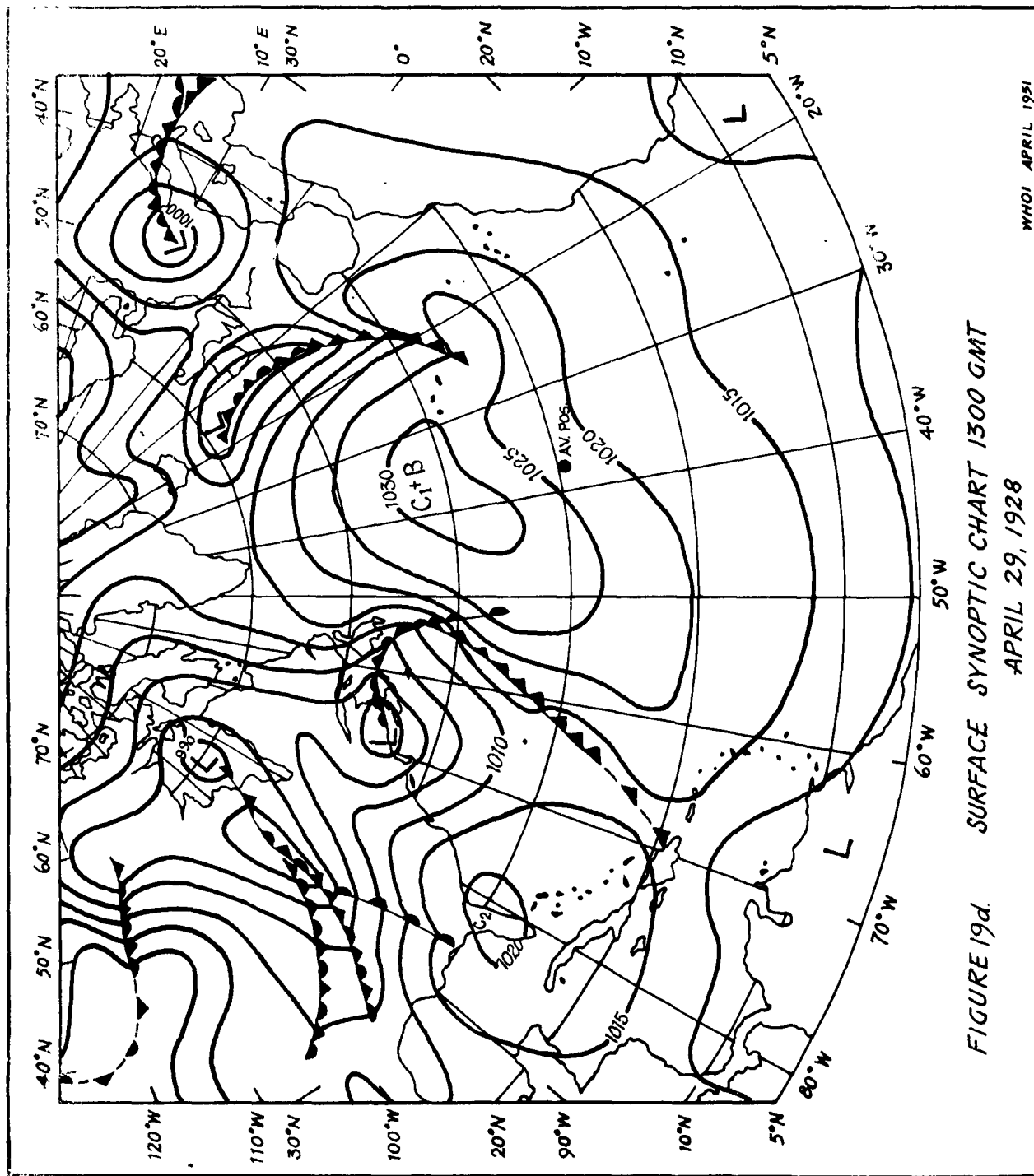


FIGURE 19d. SURFACE SYNOPTIC CHART 1300 GMT
APRIL 29, 1928

WMOI APRIL 1951

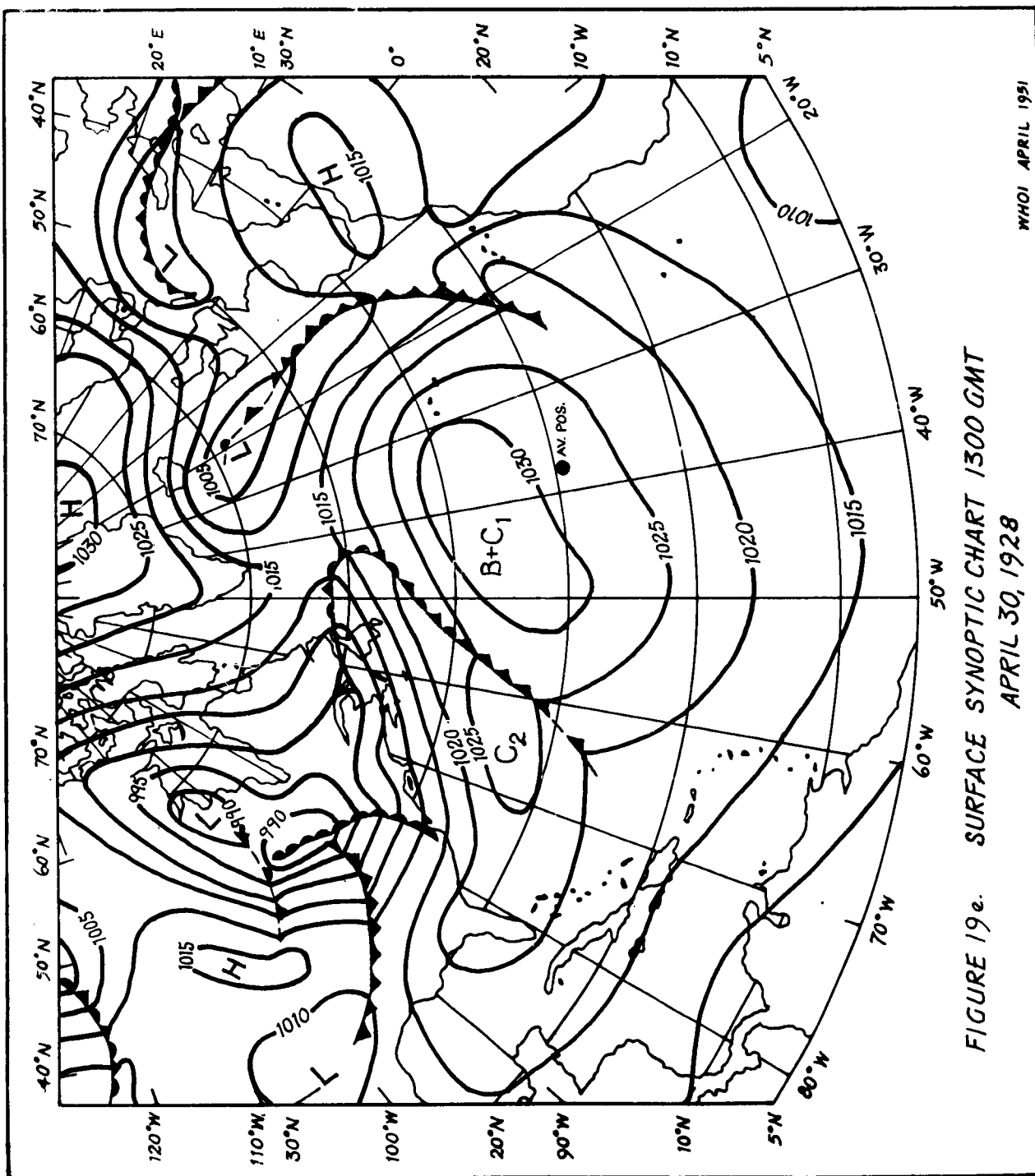
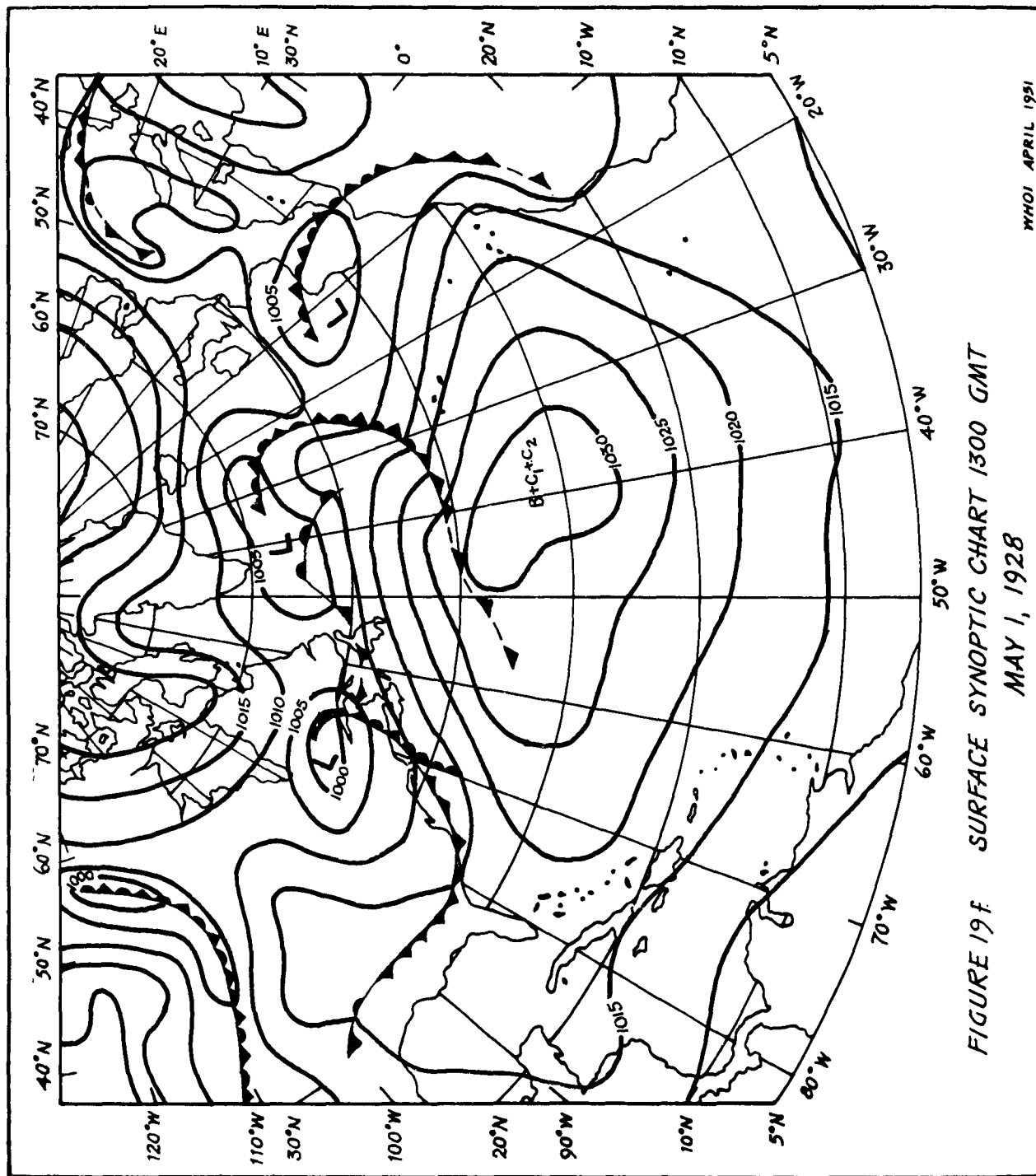


FIGURE 19c. SURFACE SYNOPTIC CHART 1300 GMT
APRIL 30, 1928



The low in Figure 13 has a mean diameter of about 2,500 nautical miles, while that of Figure 14 is about 800 miles across. The extent of the interruptions to normal circulation caused by these 2 lows is best described by the figures themselves. The winter frequency for stagnant lows runs around 30% and the summer frequency is about 15%, but the yearly deviation from the mean frequency is large.

Linkage

When a cold continental high nears the North Atlantic, its circulation links in some measure with that of the Bermuda-Azores High causing an interruption to normal circulation. Such linkage can take place along the North American east coast, in the Greenland-Iceland region, along the west coast of Europe, and along the northwest coast of Africa. Considerable interruption by linkage is seen on some 30% of maps in summer and 50% in winter. Though these figures are higher than those for stagnant lows, linkage is ranked 3rd because in many of its cases the sector affected is comparatively small.

Figures 15, 16, 17, and 18 are cases of linkage showing first a small area, then gradually larger areas affected.

Two series of maps with linkage sequences are given. The first sequence is the uniting of a cold continental high with the Bermuda-Azores High and the second shows replacement of the Bermuda-Azores High by a cold continental high.

Uniting

The first sequence begins on April 26, 1928. In the course of 5 days a cold continental high (C) situated over Winnipeg travels southeast and joins the Bermuda-Azores High. While en route, it is split into two parts, C₁, and C₂, which unite with the Bermuda-Azores High at different locations and times. On the 26th, the Bermuda-Azores High is centered at 31°N., 36°W., about 130 miles from its normal position (29½°N., 38°W.). After uniting with C, southeast of Nova Scotia it is centered at 40°N., 44°W., some 700 miles from the normal center. It then moves south and after uniting with C₂ east of Bermuda it heads east again toward its normal position. The interruptions are of two categories: (1) deflection of isobars (winds) to include the approaching C, and C₂, and (2) eccentric displacement of the whole network. These may be seen in Figures 19, a through f. Note the weakened gradient in the Trades in Figure 19d.

² In this paper, the polar ice cap and Greenland are considered as continental in contrast to the open ocean.

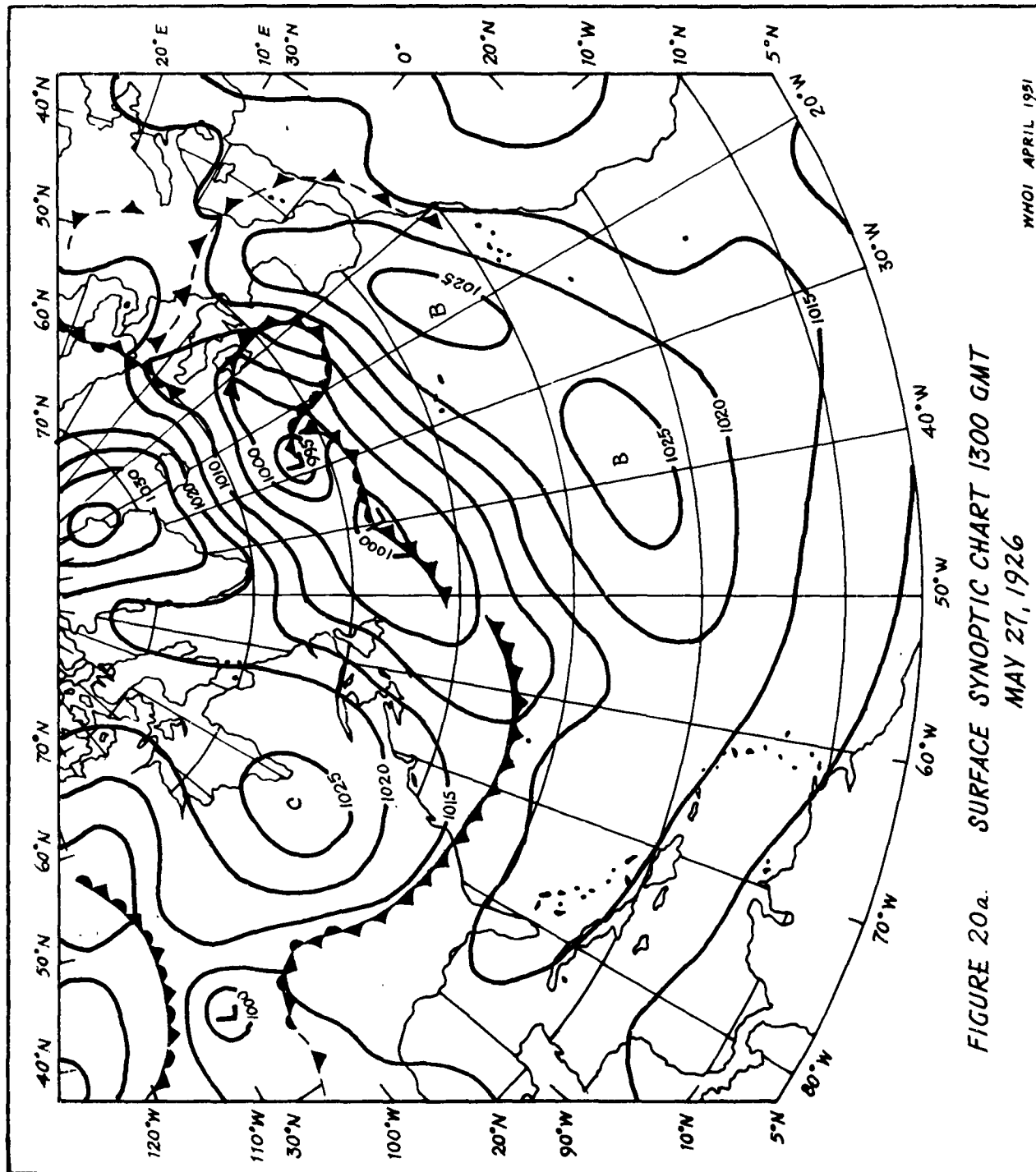
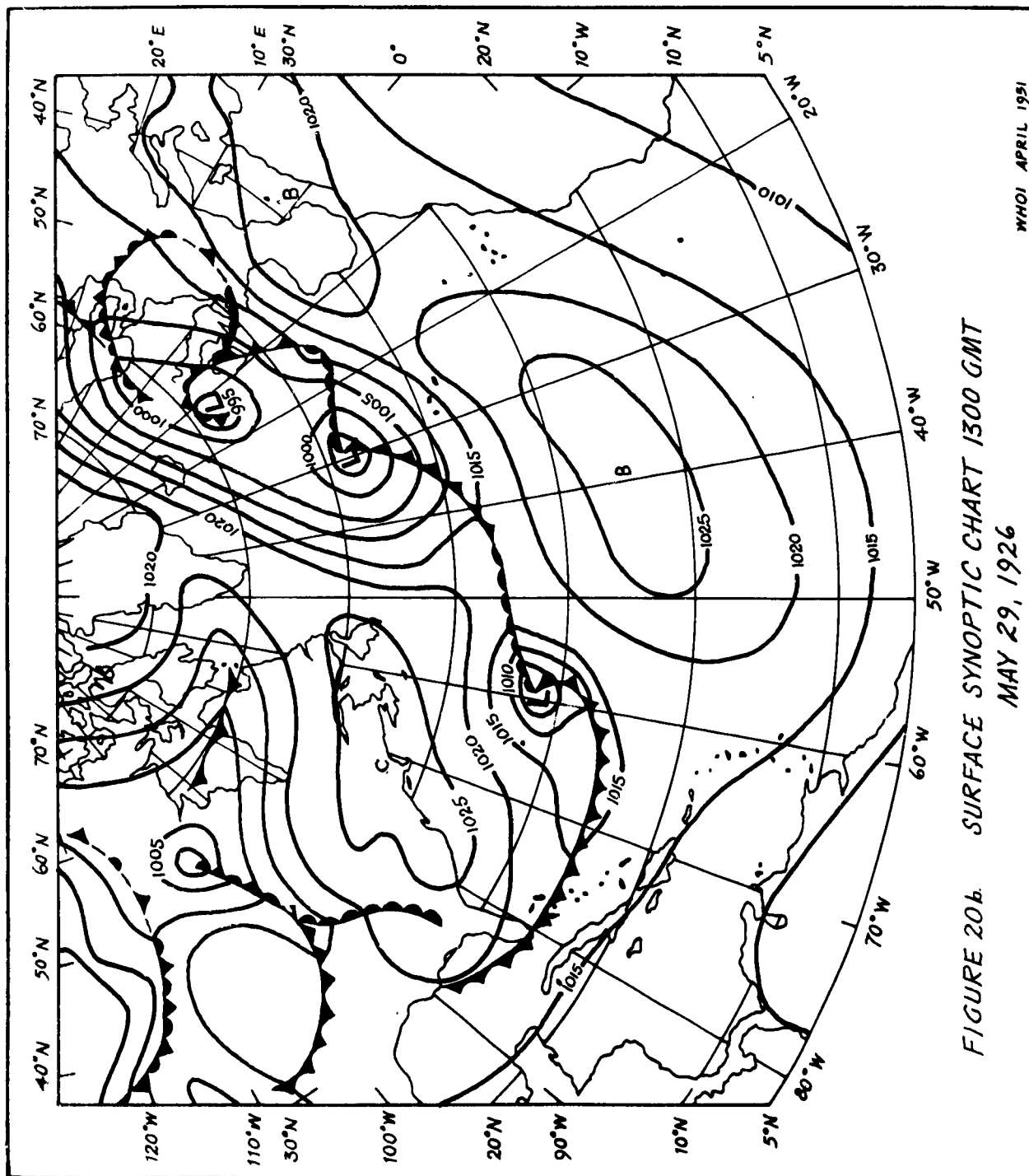


FIGURE 20a. SURFACE SYNOPTIC CHART 1300 GMT
MAY 27, 1926



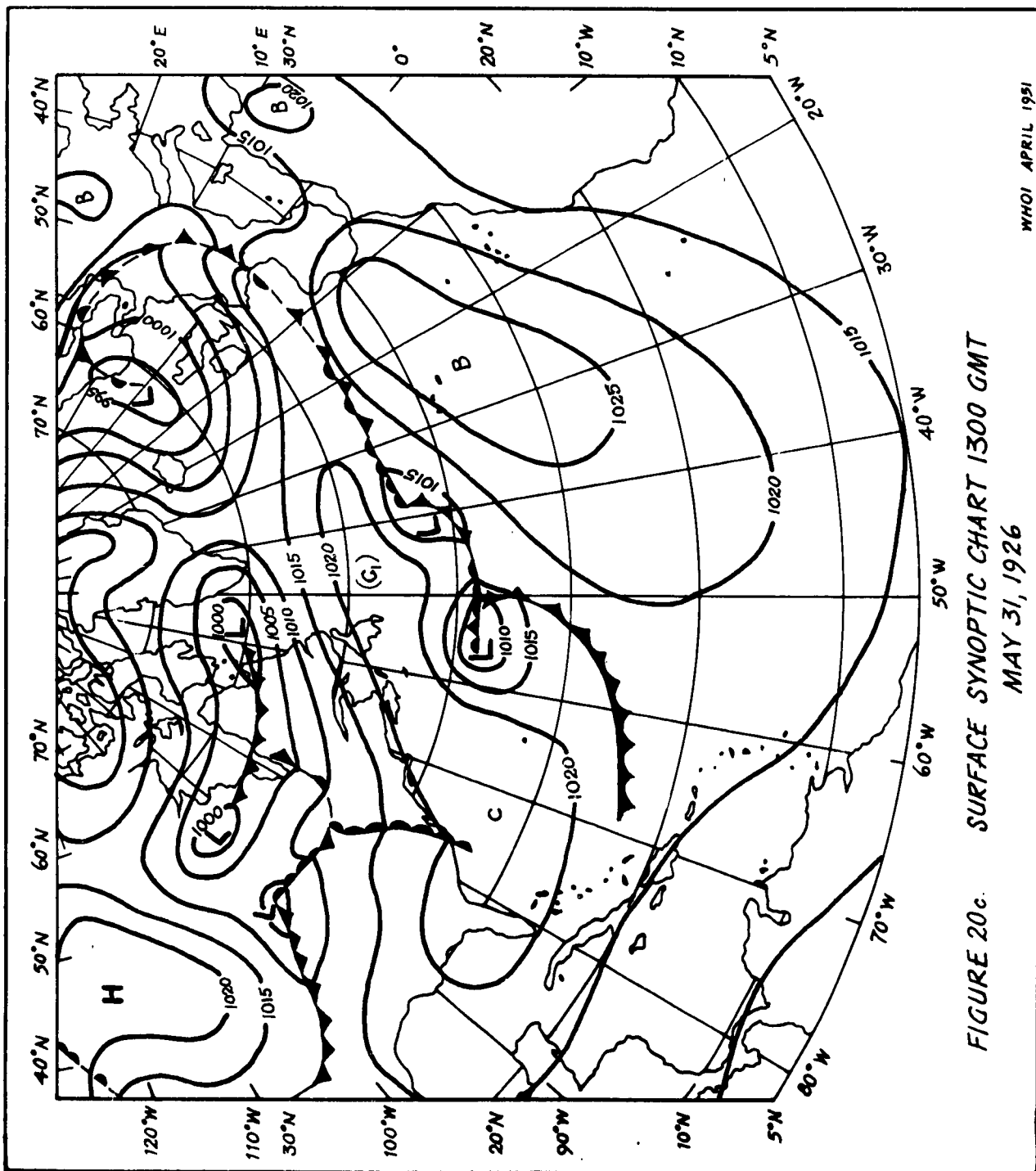
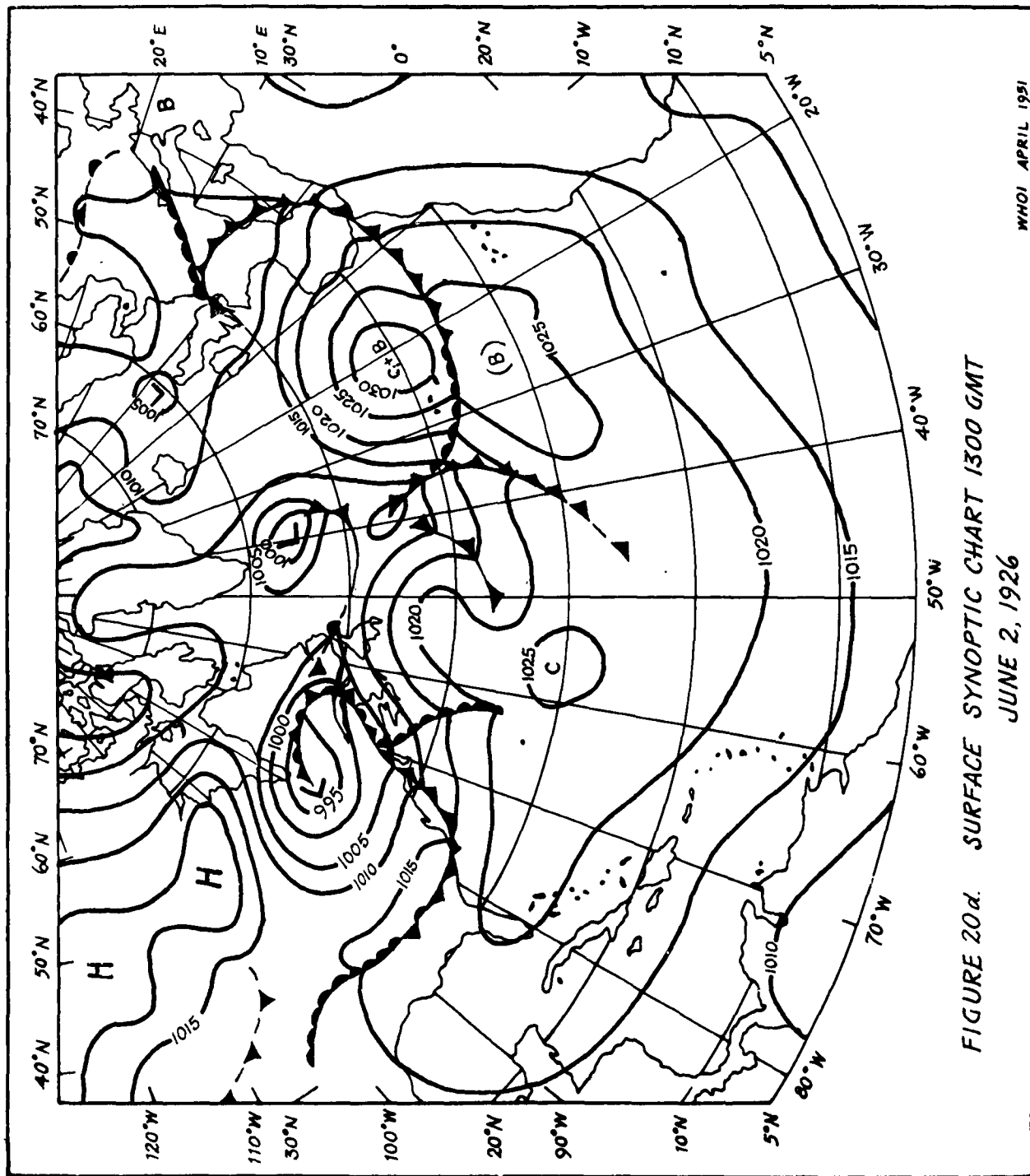
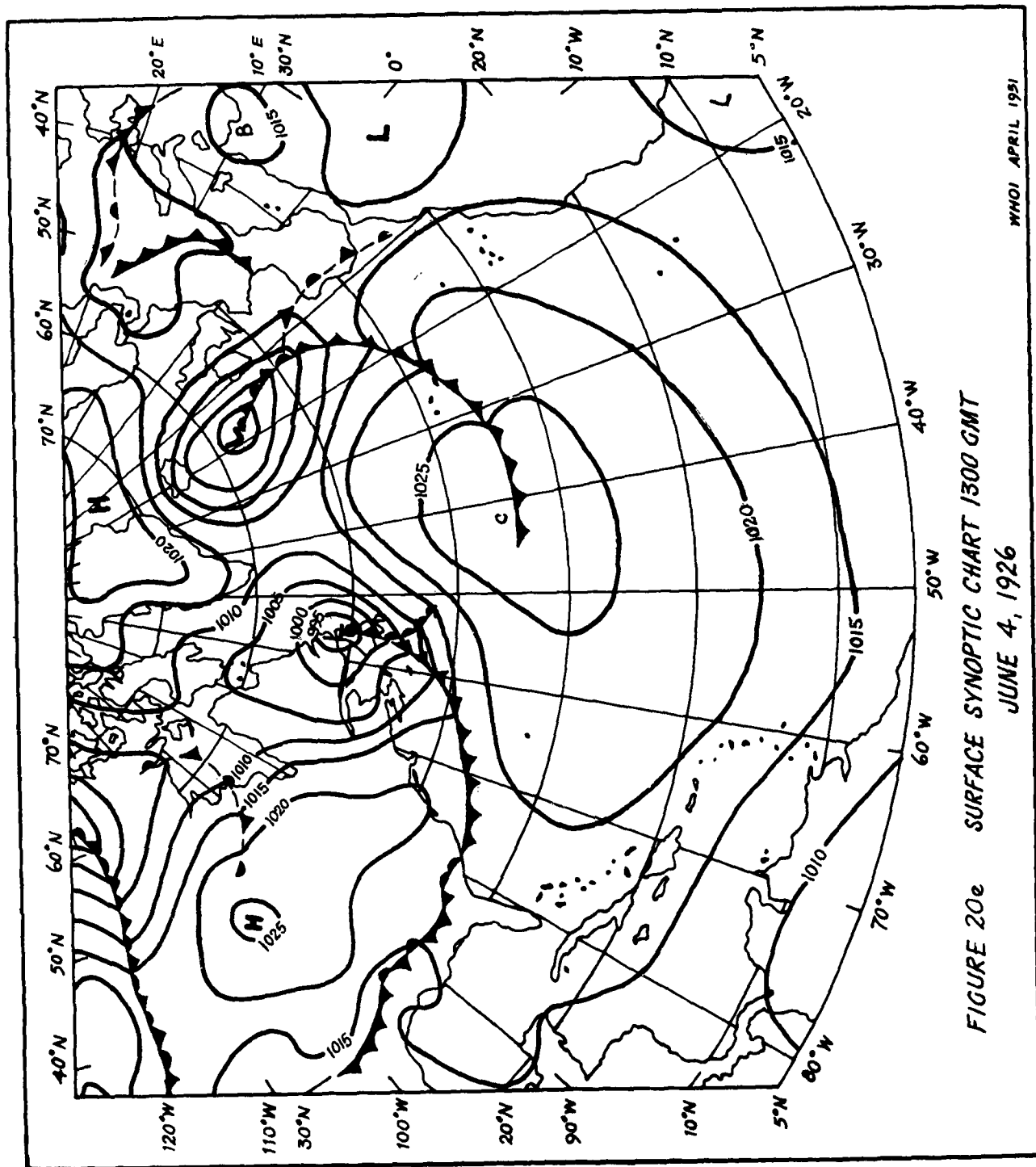
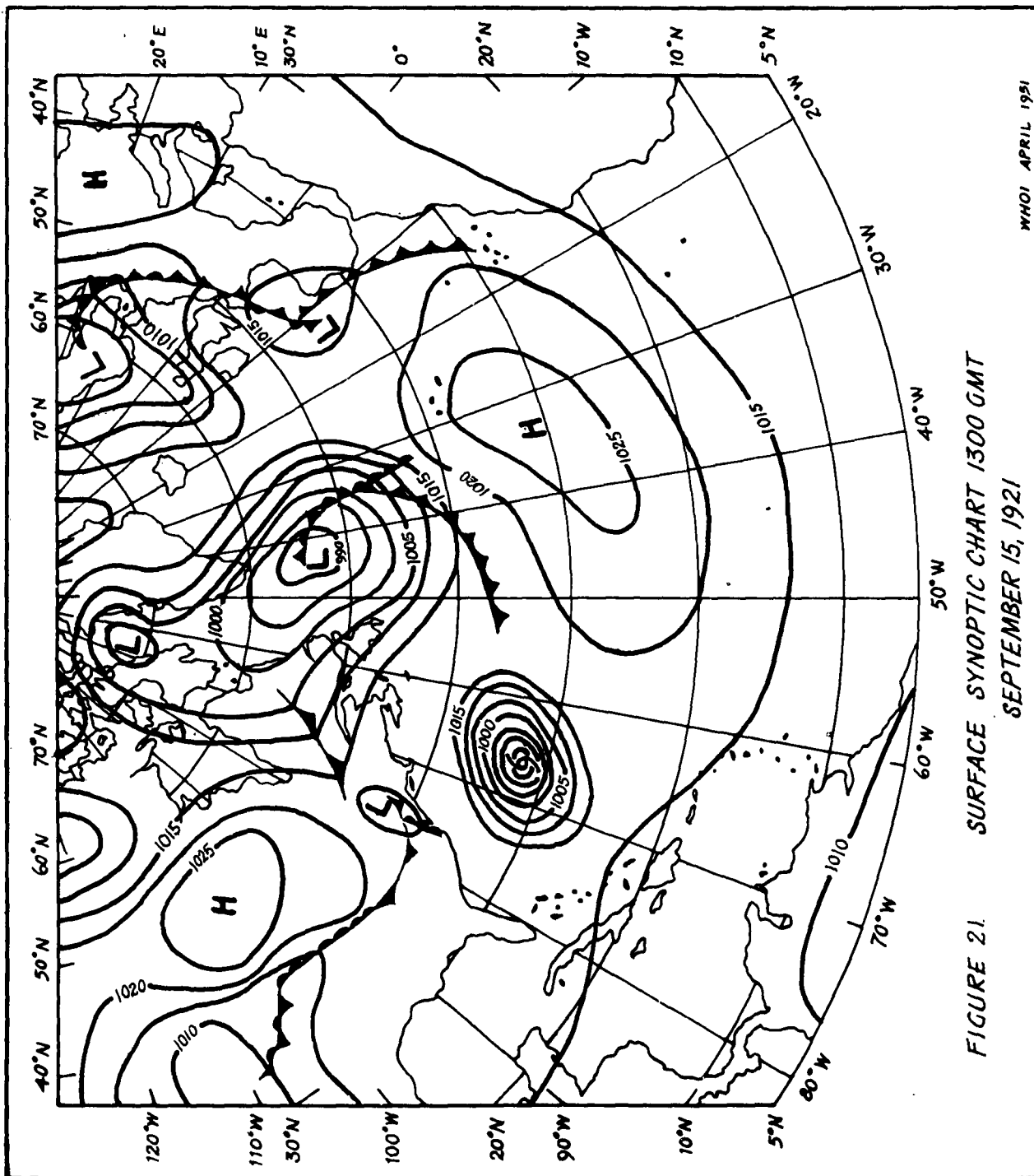


FIGURE 20c. SURFACE SYNOPTIC CHART 1300 GMT
MAY 31, 1926







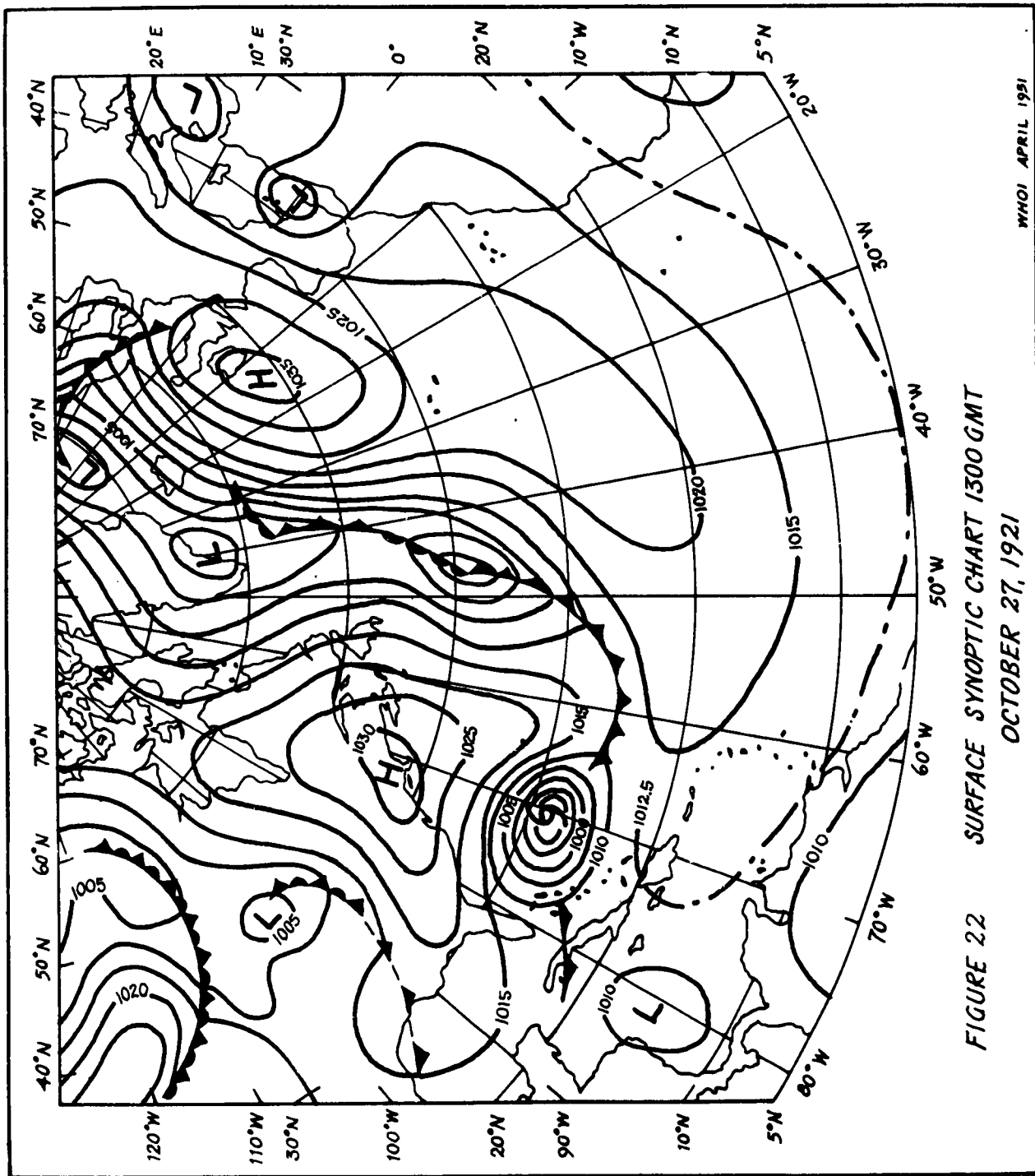


FIGURE 22 SURFACE SYNOPTIC CHART 1300 GMT
OCTOBER 27, 1921

Replacement

A replacement sequence beginning on May 27, 1926 is illustrated in maps 20, a through e. In this sequence a cold continental high (C) migrates southeast across the Great Lakes behind a cold front. In bulldozer fashion it pushes* the Bermuda-Azores High (B) eastward into Europe and the Mediterranean and on June 4th, it is centered at 35°N., 40°W., having completely replaced B. Significant is the fact that the cold front refused to dissolve and allow a union of C and B. In the course of the replacement, C has gradually transformed into a warm high and B into several small cold highs. (Note the small section C, which after being squeezed out to the eastward manages to unite with B north of the Azores).

Hurricanes

The fourth type of interruption is associated with hurricanes. Although the diameter of a typical hurricane can cover only a small part of the periphery of the Bermuda-Azores High, a hurricane is often surrounded by a much larger area of slack gradient, so that it is common for the normal circulation to be interrupted over a larger part of its arc. Furthermore, linkage of the Bermuda-Azores High to a continental high in the direction of England or France often begins a few days before the appearance of a hurricane and sometimes continues while the hurricane moves north off the U. S. east coast. While the interruption to normal circulation in the immediate vicinity of a hurricane can be said to be caused by the hurricane, the large area of slack gradient and the linkage to the northeast can be called merely associated phenomena, not traceable to the hurricane as a cause. The influence of hurricanes is confined to the months from May through November with a maximum frequency in September. The number of hurricanes per year varies so much that it is difficult to estimate a percentage of frequency for this type of interruption. Perhaps 10% is a fair figure for the active period. The duration of interruption by one hurricane varies from about five days to two weeks depending on path and speed. In the situation of September 15, 1921 (Fig. 21), the hurricane near Bermuda is about 800 miles in diameter. Beyond its edge is an area of slack gradient extending from Newfoundland to the Caribbean. A weak ridge extends northeastward from the Bermuda-Azores High to England, but the circulation in the eastern Atlantic and Trade Belt is good. In Figure 22 the slack area is confined to the Caribbean. The Bermuda-Azores High is linked up with a high pressure circulation extending across the British Isles into Russia. There is a fairly normal flow from Portugal along the African coast which continues in normal Trades westward to about 50°W. But here it is deflected northeastward

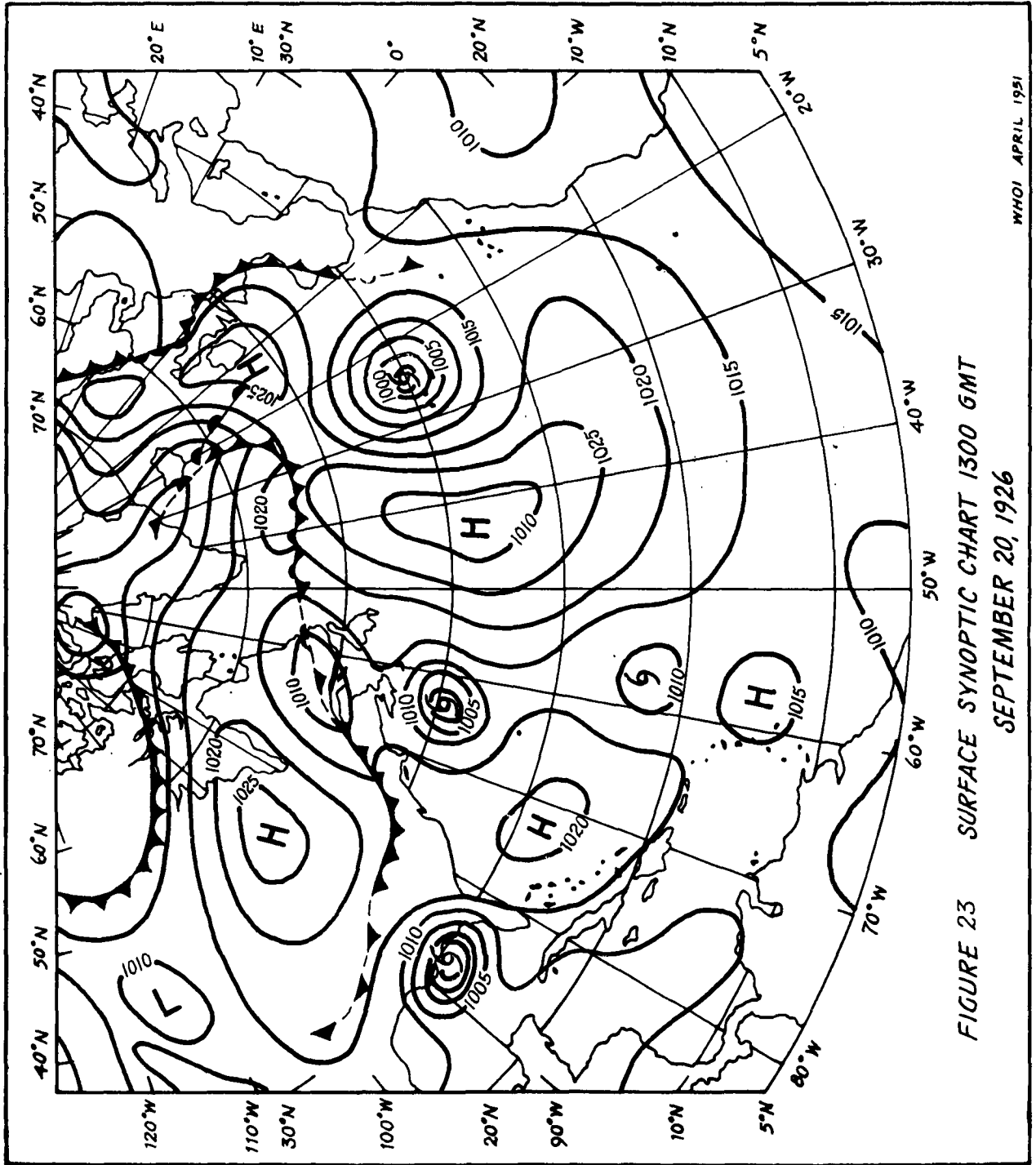


FIGURE 23 SURFACE SYNOPTIC CHART 1300 GMT
SEPTEMBER 20, 1926

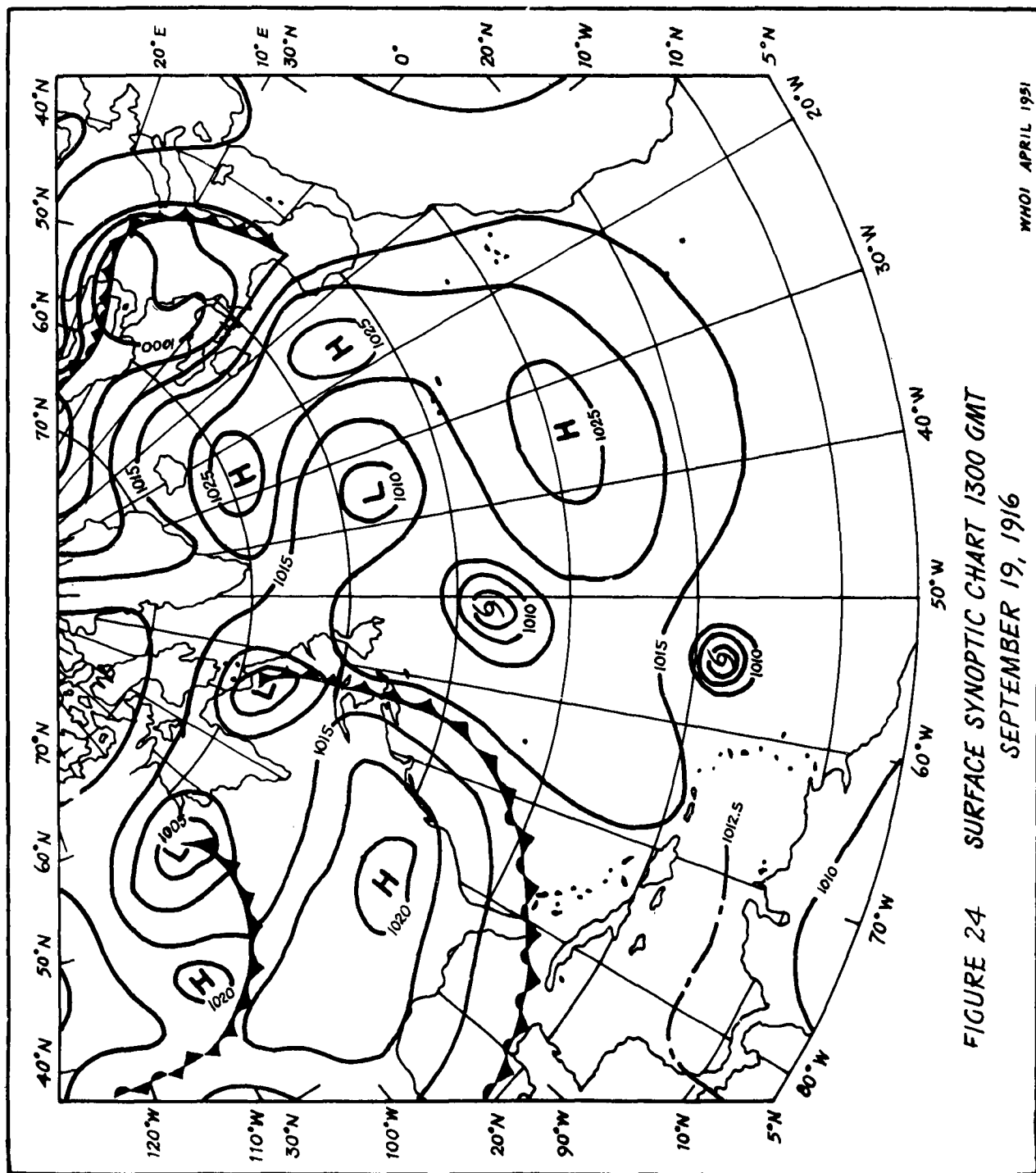


FIGURE 24 SURFACE SYNOPTIC CHART 1300 GMT
SEPTEMBER 19, 1951

instead of carrying on into the Caribbean.

Though on any one map the number of hurricanes is rarely in excess of two, as many as five on one map can be seen in the Historical Series. Figure 23 is one of these rare cases of more than two simultaneous hurricanes, having four.

Three of the four hurricanes of Figure 23 have interrupted the normal circulation to the extent that only short segments remain, viz: Trades from Africa to 50°W. and from Puerto Rico to Florida, a weak west end circulation and Westerlies for a short stretch off Newfoundland.

To show that more than one type of interruption can be presented on any given map, Figure 24 is included. It contains two hurricanes, one stagnant low, linkage to a cold high and a frontal interruption.

Summary

The Bermuda-Azores High produces* a clockwise wind circulation over the surface of the North Atlantic Ocean. This circulation is oval-shaped with the long axis running east-west on the average. The annual average position of the center is about 600 miles southwest of the Azores, and the average positions by months are all within about 700 miles of the annual average center. The average wind flow produced* runs northward from the Antilles to north of Bermuda, eastward to between the Azores and Portugal, southward along the African coast to the Cape Verde Islands, then westward to the Antilles. The winds are steadiest from Africa to the Caribbean (the Trade Winds). The strongest forces are found in the Westerlies, but variability of direction in this area reduces the average gradient to an amount about equal to that in the Trades. Variable directions reduce the gradient in the west end to a very weak average, but do not affect the east end as much. Air diverges from the high, cross-isobar at an average angle of some 20°. The angle is larger near the Cape Verde Islands and smaller in the Westerlies.

Daily situations can be divided into two nearly equal categories containing: (1) those which show a circulation resembling the average and (2) those in which the circulation has been interrupted by normal meteorological phenomena. The interrupting phenomena are by order of importance: fronts, stagnant lows, linkage of cold continental high cells to the Bermuda-Azores high, and hurricanes.

The interruptions have a persistence of 1 to 6 weeks and take the form of wind directions turned from normal and of gradients weaker than normal.

Interruptions due to hurricanes are most frequent in September, but can occur anytime in the period from May through November. Interruptions due to fronts, stagnant lows, and linkage are more frequent in the winter. This latter is especially true with respect to the Trades.

Due to fewer interruptions and to higher center pressure, the circulation about the Bermuda-Azores High is stronger in summer than in winter.

Future Research

While, except for one instance, reference to ocean phenomena has been studiously avoided, it is felt that further research may uncover relationships between meteorological and oceanographic phenomena within periods of time varying from 5 days to 2 years. This research should involve the measurement of wind components parallel to the normal circulation and comparison of these components with oceanic circulation.

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